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Sewage Sludge versus Commercial Methods for Reclaiming Strip-Mine Soils

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SEWAGE SLUDGE VERSUS COMMERCIAL METHODS FOR RECLAIMING STRIP-MINE SOILS

by

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Municipal sewage sludge has been reported to be useful in reclaiming strip-mined soils for revegetation and row crop agriculture. Commercial methods using top soil replacement, lime and fertilizer have also been reported to be successful in reclaiming (revegetating) strip-mined soils. This study was carried out to determine:

1. The relative costs of sewage sludge versus commercial methods for reclaiming strip-mined soils.
2. The feasibility of using sewage sludge and commercial methods for reclaiming strip-mined soils.
3. The environmental impact of using municipal sewage sludge and commercial methods for reclaiming strip-mined soils.

This study involved an in-depth investigation of the reclamation of strip-mined sites using commercial methods and sewage sludge, including site visits to two (2) strip-mined sites. Because of the unavailability of both adequate environmental and cost information for sites that had been reclaimed using commercial methods, a literature evaluation was used to compile the environmental information, while actual cost data were used for commercial methods.

This study has demonstrated, based on the available data, that commercial methods and sewage sludge can be both successfully used to reclaim strip-mined soils with no adverse environmental impacts. It was concluded that selection between the use of commercial methods and sewage sludge for reclaiming strip-mined soils should be based upon site specific evaluations of costs, social, political, and aesthetic factors. The report gives unit costs for the various reclamation procedures used for commercial methods and sewage sludge, but these costs must only be used as a guide in determining the unit costs for the reclamation of a specific site.

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FOREWORD

The U.S. Environmental Protection Agency (U.S. EPA) was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report was prepared to assist those who are considering or must reclaim land which was strip mined. The costs and environmental effects of using municipal sewage sludge or commercial products (lime, fertilizer, etc.) to reclaim strip-mined land are documented so that an informed decision can be made between the two reclamation methods.

Francis Mayo, Director
Municipal Environmental Research
  Laboratory
Cincinnati, Ohio

ABSTRACT

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CONTENTS

Disclaimer ii
Foreword iii
Abstract iv
Figures viii
Tables ix
Abbreviations and Symbols xii
Acknowledgments xiv

1. INTRODUCTION 1
    BACKGROUND 1
    METHODOLOGY 3
        Environmental Monitoring Data 3
        Cost Data 3
        Institutional, Social and Environmental Analysis 4

2. CONCLUSIONS 5

3. RECOMMENDATIONS 7

4. COMPONENTS OF COST COMPARISON ANALYSIS 9
    INTRODUCTION 9
        Case 1 9
        Case 2 10
        Case 3 10
    COST COMPONENTS 10
        Capital Cost Items 10
        Maintenance and Operation Costs 10
    PRESENTATION OF COST DATA 11
        Cost Comparison Analysis Methodology 11
        Cost and Benefits 12
    SEWAGE SLUDGE VERSUS COMMERCIAL METHODS 13

5. CASE STUDIES ANALYSIS 15
    RECLAMATION USING SEWAGE SLUDGE 15
        Fulton County Site 15
            General Topography of Fulton County Site 18
            Geological Characteristics 18
            Soil Characteristics 18
            Sludge Application at the Fulton County Site 20

CONTENTS (continued)

Environmental Monitoring Data................ 20
    Nutrient application.................... 24
    Soil response........................... 24
    Crop response........................... 28
    Regulatory restrictions on crops........ 31
    Runoff retention basin effluent quality. 32
    Groundwater quality..................... 33
    Surface water quality................... 33
    Permits................................. 33
Social and Aesthetic Issues................. 36
Cost and Benefits........................... 36
Summary..................................... 39
Ottawa/Buffalo Rock Strip-Mined Site............. 40
    Description of the Site and Reclamation Project.................................. 40
    Site Geology and Soil Characteristics........ 41
    Treatment and Handling of Sludge Used on the Ottawa Site........................... 42
    Description of the Reclamation of the Ottawa Site............................... 42
    Environmental Monitoring Data................ 44
        Sludge quality.......................... 44
        Surface water........................... 44
        Groundwater analysis.................... 44
    Costs....................................... 48
    Summary..................................... 52
RECLAMATION USING COMMERCIAL METHODS.................. 53
    Background...................................... 53
    Characteristics of the Spoil Material............ 53
    Crops and Crop Responses......................... 54
    Water Quality.................................... 58
    Summary.. 68
    Cost Estimates for Reclaiming Strip-Mined Sites Using Commercial Methods....................... 68
        Cost Information from Several Sites.......... 70
        Cost Estimate-Reclaiming Steeply Sloped, Acid Soil, Strip-Mined Land................ 75
        Cost Estimate-Reclaiming Moderately Sloped, Neutral Soil, Strip-Mined Land............. 76

6. COMPARISON OF COSTS - SLUDGE RECLAIMED SITES VERSUS COMMERCIALLY RECLAIMED SITES.............................. 78
    INTRODUCTION... 78
    COST COMPARISON-SLUDGE VS. COMMERCIAL METHODS.......... 79

CONTENTS (continued)

7. INSTITUTIONAL, SOCIAL, AND ENVIRONMENTAL ANALYSIS........... 85
INSTITUTIONAL AND SOCIAL ANALYSIS...................... 85
ENVIRONMENTAL ANALYSIS.............................. 86

References.. 88

Appendices

A. Geological properties of the Fulton County Site 91
B. Plant nutrient levels in soil at the Fulton County Site 93

FIGURES

Number		Page
1	The holdings and locations of the land purchases made by the District at Fulton County, Illinois.........	17
2	Spatial distribution of soil areas at the Fulton County, Illinois site..................................	19
3	The District's typical field design with runoff water capture system, Fulton County, Illinois..	21
4	Lagoon sludge removal at the West-Southwest sewage treatment plant...	43
5	Plant cover and associated rooting depths on the central Illinois coal refuse pile.......................	57
6	Short-term water responses to the 1977 reclamation, Ottawa, Illinois site................................	63
Appendix		
7	Typical stratigraphic profile in the project area.......	92

TABLES

Number		Page
1	Major Cost Items Used in Cost Comparison Analysis......	14
2	Range of the Principal Constituents of the Digested Sludge Applied to Fulton County Fields from May 6 to October 21, 1979 and the Mean Content Per Dry Metric Ton....................................	22
3	Annual and Accumulative Sludge Dry Matter Application for Selected Fields at Fulton County, Illinois Land Reclamation Site.........................	23
4	Sludge Solids and Nutrient Loadings to Three Representative Fields at the Fulton County Site.............	25
5	Soil pH in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site.................	26
6	Soil Organic Carbon in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site.......	27
7	Metals Content of Mine Spoil at the Fulton County Site Before and After Sludge Application....................	28
8	Corn Yields in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site.................	29
9	Cadmium in Corn Grain from Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site..........	30
10	Cadmium in Corn Grain Grown in 1979 on Fulton County Fields Not Amended with Sludge.........................	31
11	Runoff Water Quality from Field Runoff Retention Basins......................................	32
12	Mean Water Quality of Well Numbers 14 and 17 at the Fulton County Site....................................	34
13	Mean Surface Water Quality of Sampling Points S1 and S2 at the Fulton County Site......................	35

TABLES (continued)

Number		Page
14	Annual and Unit Costs for Fulton County Project (1980 Dollars)..	38
15	Fulton County Annual Monitoring Costs (1980 Dollars)..	39
16	Constituents in Digested Lagooned Sludge Shipped to the Ottawa Strip-Mined Site.........................	45
17	Surface Water Quality at the Ottawa Strip-Mined Site..	46
18	Groundwater Analysis at the Ottawa Strip-Mined Site..	47
19	Actual Costs in 1980 Dollars for Reclaiming the 0.809 ha Ottawa Strip-Mined Site................................	49
20	Costs in 1980 Dollars of Environmental Monitoring of the 0.809 ha Ottawa Strip-Mined Site...............	50
21	Costs in 1980 Dollars for Reclaiming the Remaining 59.9 ha Ottawa Site......................	51
22	Crop pH Requirements...................................	55
23	Yields of Forage Mixtures Produced on Strip-Mined Lands in Illinois....................................	56
24	Infiltration Rates of Four Spoil Types Under Three Different Physical Conditions (Level, Strike-off, and Ridges), and Two Types of Cover (Bare and Grass-Legume Vegetation).............................	59
25	Summary of Water Quality at Three Abandoned Mine Sites in Illinois...............................	60
26	Groundwater Quality After Reclamation, Ottawa, Illinois Site..	66
27	Conditions for Cost Estimate - Commercially Reclaiming a Steeply Sloped, Acid Soil, Strip-Mined Site..........	69
28	Conditions for Cost Estimate - Commercially Reclaiming a Slightly Sloped, Neutral Soil pH, Strip-Mined Site...	69

TABLES (continued)

Number Page

29 Unit Costs in 1980 Dollars for Reclaiming Four Strip-Mined Sites in Ohio.................................... 70

30 Costs in 1980 Dollars for Strip-Mined Reclamation in the Western United States............... 71

31 Costs in 1980 Dollars of Grading and Backfilling in Appalachia and the Midwest.......................... 72

32 Estimated Costs in 1980 Dollars to Recontour 12 Abandoned Strip-Mined Sites in the United States....... 73

33 Costs in 1980 Dollars for Growing Corn on Reclaimed Mine Land in Iowa..................................... 74

34 Cost Estimates for Scenario 1 Described in Table 27.... 75

35 Cost Estimates for Scenario 2 Described in Table 28.... 76

36 Costs for the Ottawa and Fulton County Sites for Comparison with Commercially Reclaimed Sites........... 80

37 Costs for Commercially Reclaiming Two Sites............ 81

38 Costs for Various Reclamation Objectives Based Upon Unit Costs for the Fulton County and Ottawa Sites Using Sewage Sludge.................................. 82

39 Costs for Various Reclamation Objectives Based Upon The Two Scenarios Described in Tables 27 and 28 Using Commercial Methods............................... 83

Appendix

B-1 Available Mineral N in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site....... 94

B-2 Available P in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site.......... 95

B-3 Available K in Selected Sludge Amended Fields at Fulton County, Illinois Land Reclamation Site.......... 96

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD_5 --biochemical oxygen demand
cm --centimeter(s)
cm^3 --cubic centimeter(s)
cm/sec --centimeter(s) per second
cnt/100ml --counts per milliliter(s)
E.C. --electrical conductance
g --gram(s)
g/cm --gram(s) per centimeter
ha --hectare(s)
IEPA --Illinois Environmental Protection Agency
kg --kilogram(s)
kg/ha --kilogram(s) per hectare
kl/ha --kiloliter(s) per hectare
km --kilometer(s)
l --liter(s)
m^3 --cubic meter(s)
m --meter(s)
μg/g --microgram(s) per gram
mhos --1/ohm(s)
μmhos/cm --μmhos/centimeter
M&O --maintenance and operations
mg/l --milligram(s) per liter
ml --milliliter(s)
No. --number(s)
NH_3-N --ammonia nitrogen
ppm --parts per million
μS/cm --"S" stands for Siemen's units which is the metric notation for specific conductance, i.e., same as μmhos/centimeter

TDS --total dissolved solids
TKN --total Kjedahl nitrogen
TS --total solids
TSS --total suspended solids
t --metric ton(s)
t/ha --metric ton(s) per hectare
t/ha/y --metric ton(s) per hectare per year
U.S. EPA --United States Environmental Protection Agency

Vol. --volume
WSW --West - Southwest Treatment Plant

SYMBOLS

Al --aluminum
Ca --calcium
$CaCO_3$ --calcium carbonate
Cd --cadmium
Cl --chlorine
CN --cyanide
Cr --chromium
Cu --copper
Fe --iron
FeS --iron pyrite
H --hydrogen
Hg --mercury
HCl --hydrochloric acid
K --potassium
Mg --maganesium
Mn --manganese
N --nitrogen
Na --sodium
NH_3 --ammonia
P --phosphorus
Pb --lead
% --percent
$\leq$ --less than or equal to

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SECTION 1

INTRODUCTION

BACKGROUND

The surface mining process for extracting coal is called strip mining. This process is accomplished in two ways - area stripping and contour stripping. Area stripping is practiced in relatively flat terrain and is used to extract near-surface bedded deposits. This technique involves removing the overburden using large shovels, draglines, or bucket wheel excavators. In smaller operations bulldozers may be used. The overburden from the first cut is placed on unmined land adjacent to the cut and the coal is then removed. This process is repeated (a parallel cut is made, the overburden from subsequent cuts is placed into those pits previously excavated) across the property until the depth of overburden and coal characteristics make the mine uneconomic, or until property boundaries are reached. Disposal and burial of preparation-plant wastes, brush, trees, toxic and other materials are also accomplished in the overburden placing process. The terrain or spoil ridges after area stripping has been characterized as resembling gigantic washboards (1,2).

Contour stripping is practiced in hilly terrain and mainly to extract coal that crops out along the sides of steep hills. Starting at the outcrop and proceeding around the hillside, the contour stripping process involves removing the overburden over the coal seam, followed by the coal. Successive cuts are made until the overburden becomes too great to permit the coal to be recovered economically. Handling of the overburden has in some instances created a problem because of little working space available. Overburden removal was accomplished by casting the overburden down hill slopes. This is rarely done anymore, rather the trend is now towards replacing overburden immediately after coal removal (1,2).

Strip mining operations typically leave steeply sloping spoil or waste mounds depleted of plant nutrients and organic matter. These mounds rarely support vegetation; are easily eroded causing contamination of nearby water supplies, and the destruction of wildlife habitat; and prevent rapid productive redevelopment of strip-mined lands. In response to citizen concern and environmental damage caused by thousands of acres of abandoned and useless land, and hundreds of miles of streams contaminated by mine drainage and silt, reclamation of the mined sites was required in many States by State law (3). In 1977, the U.S. Government passed PL 95-87, "Surface Mining Control and Reclamation Act of 1977". Section 508 of the Act stipulates that the reclamation plans submitted as part of the application permit must adhere to applicable regulatory requirements (4). Where State laws are more stringent than the Federal, those must be adhered to. Section 508 of the Act sets forth the general requirements of the reclamation plan. Restoring the capability of the residual spoils to accomodate a vegetative cover is the major objective of strip-mined reclamation. In general, reclamation includes backfilling, soil stabilization, compacting, and grading; removal, storage, and redistribution of topsoil, subsoil, and other material; revegetation, environmental protection and environmental monitoring. The extent of reclamation varies. Reclamation can be implemented to the extent necessary for erosion control only, for revenue producing crop production and/or for multi-recreational uses. While some reclamation goals have been achieved with site grading, preparation and seeding only, most of the reclamation goals must include site fertilization.

Reclamation has been achieved successfully through the use of various commercial methods. Sewage sludge has also been shown to be well adapted for this type of reclamation. Reclamation using commercial methods relies on the use of products readily available in the open market. Inorganic fertilizers (containing the essential plant nutrients of nitrogen (N), phosphorus (P), and potassium (K)), lime, and topsoil are used to restore the fertility of strip-mined lands. Lime may be used to raise the soil pH to levels where plant growth is possible. Topsoil may be added in varying amounts to provide needed organic matter for soils. Organic matter tends to increase the water holding capacity of rapid draining soils while, on the other hand, it will increase the water infiltration rate of soils which tend to hold water. Soil organic matter, therefore, will prevent the soil from drying out during periods between rains, and keep the soil from becoming waterlogged during raining periods.

Municipal sewage sludge is the residue remaining after the treatment of municipal wastewater. Sewage sludge, because it has its origin in part from agricultural products and in part human manure, contains organic matter and the essential plant nutrients of N, P, and K. In addition, the sludge usually has a high alkalinity content which can be used to neutralize acid soils. Thus, sewage sludge contains naturally the same products that are purchased to reclaim strip-mined lands using commercial methods. The use of sewage sludge, where possible, in lieu of commercial products for strip-mined reclamation would help solve, in part, one of the biggest problems facing many municipalities; namely, the management of sewage sludge. Sewage sludge is a valuable resource, and would be beneficially utilized in the reclamation process. Although sewage sludge contains some materials which make it useful in strip-mined reclamation, it also contains various trace elements, most notably metals, which could cause potential environmental problems. While many studies have shown that those potential problems would vary with the quality of sludge being used, environmental monitoring data for sludge application sites are necessary for documenting environmental changes to satisfy Federal and State regulatory requirements.

The purpose of this study was to compare the costs and benefits, and environmental impacts associated with reclaiming strip-mined lands using sewage sludge and commercial methods. The institutional, social, and environmental advantages and disadvantages of each method for strip-mined land reclamation were also compared and are documented.

METHODOLOGY

This cost comparison analysis was performed by comparing costs and benefits, and environmental monitoring data obtained for striped-mined lands being reclaimed using sewage sludge and for those being reclaimed using commercial methods. The data used in this study for reclamation with sewage sludge are for two sites in Illinois--Ottawa and Fulton County. Because of the unavailability of complete, parallel information for sites being reclaimed using commercial methods, published data and an evaluation of those data were utilized to obtain environmental monitoring data, and the cost and benefit data were gathered from real sites and then applied to possible sites.

Environmental Monitoring Data

The environmental monitoring data used in this analysis consisted of the following:

1. Physical, chemical and biochemical properties of the applied sludges,
2. Site characteristics of the strip-mined sites before and during reclamation,
3. Crops and crop responses to reclamation methods,
4. Characteristics of runoff and surface water quality before, during, and after reclamation,
5. Groundwater quality before, during, and after reclamation, and
6. Air quality information (for sludge reclaimed sites.)

Cost Data

The cost components used for the costs and benefits analysis consisted of the following:

1. Monies Expended for Capital Costs

    a. Consulting services - engineering and legal
    b. Land costs
    c. Site preparation
    d. Equipment
    e. Buildings

2. Maintenance and Operation Costs

    a. Salaries and overhead
    b. Equipment, vehicles
    c. Supplies
    d. Fuel
    e. Application - fertilizer; sludge
    f. Farming
    g. Monitoring
    h. Transportation
    i. Miscellaneous

Institutional, Social and Environmental Analysis

The institutional, social, and environmental analysis utilized information, data, and situations resulting from the impact of the demands imposed by Federal and State reclamation requirements, data from the social and recreational benefits, and data from the physical, aesthetic and agronomic changes following reclamation.

SECTION 2

CONCLUSIONS

1. Municipal sewage sludge can be successfully used to reclaim strip-mined soil and will permit previously nonproductive soils to support vegetation including row crop agriculture.

2. Municipal sewage sludge does not adversely affect the environment when properly used to reclaim strip-mined soil.

3. Commercial methods using topsoil replacement, lime, and fertilizer can be successfully used to revegetate strip-mined sites.

4. Commercial methods do not adversely affect the environment when used in well-managed land reclamation programs provided that environmental damage is not done to the land from which the topsoil was drawn.

5. Vegetation of acid strip-mined spoils reclaimed by commercial methods may fail if the underlying soil acids migrate upward to the root zone. Should this migration occur, it may be corrected by periodic fertilization and liming.

6. Evidence is accumulating indicating that strip-mined reclamation using sewage sludge is less likely to require subsequent maintenance application than reclamation by commercial methods.

7. Unit cost figures for commercial and sludge reclamation of strip-mined sites in this report, should be used only as a guide because site specific factors can be quite variable. However, the elements of costs considered are those of primary concern for the reclamation of strip-mined sites.

8. The costs of strip mine reclamation using sewage sludge supplied free to the site are approximately equivalent to those of commercial reclamation methods using top soil, fertilizer and lime.

9. Sludge management agencies may decide to renovate strip-mined land if overall costs (including treatment, transportation, sludge application, etc. minus any compensation from the renovated land) are lower than the costs of other viable sludge management options such as incineration or landfilling.

10. Private concerns owning strip-mined land will consider sewage sludge for renovation if the costs of renovation are comparable to the those of commercial methods. It appears, therefore, that sludge management agencies will have to underwrite substantially the costs of sludge treatment and transportation in order to bring costs of sewage sludge reclamation down to that of commercial methods.

11. Any decision between using commercial methods and sewage sludge for reclaiming strip-mined sites must also weigh the social, political, and aesthetic factors as well as costs. These factors can be so significant that cost may not be an important consideration in a final decision.

SECTION 3

RECOMMENDATIONS

The following recommendations can be made based on this study:

1. In the process of selecting sewage sludge or commercial methods for the reclamation of strip-mined lands, the factors cited below should be considered:
   a. Ownership of the strip-mined property.
   b. The accessibility of the sewage sludge both in terms of quantity and reliability of supply.
   c. Sludge hauling distance to strip-mined area.
   d. The expressed or implied interest of a sewage sludge generating agency in a strip-mined site for reclamation as a short-term or long-term sludge management option.
2. In terms of comparing costs of the two options, the comparison should be developed from two perspectives:
   a. From the perspective of the strip-mined owner, and
   b. From the perspective of the sludge generator.

The strip-mined owner should compare the cost components of both practices based on the site specific situation before deciding which is more economical.

The sludge generator should compare sludge disposal costs for other viable management options with the cost of strip-mined land reclamation. Costs of reclamation can then be compared with costs for other viable disposal options. A decision, based on cost, can then be made.

3. Where possible, cost comparisons of sewage sludge versus commercial methods for strip-mined reclamation should be made for achieving the same end point conditions.

4. Many studies have been conducted to demonstrate that sewage sludge can be used to renovate strip-mined land. But, attention should now be paid to improving the cost effectiveness of this renovation technique by improving operations (such as methods of application, transportation, etc.) and by more clearly defining the level of renovations achieved by various levels of sludge application.

SECTION 4

COMPONENTS OF COST COMPARISON ANALYSIS

INTRODUCTION

The components which enter into the cost analysis of a strip-mined reclamation project may vary in number and range (cost) of site specific conditions such as physical location, topography, soil pH and type, and environmental constraints. Cost component selection may vary because of specific conditions such as site ownership (whether a large corporation or small private owner), and the level of interest displayed by a sewage sludge generating agency in obtaining strip-mined land for sludge management. In this study, the major components of the cost comparison analysis were (1) costs and benefits, (2) environmental monitoring and (3) institutional, social and environmental constraints.

Three situations not related to site specificity also appear to govern or at least strongly influence the cost components:

1. a private strip-mined owner who wishes to reclaim,

2. a sewage sludge generator (usually a public agency) wishes to use sewage sludge for reclamation but does not own the land, and

3. a sewage sludge generator owns or acquires the land to be reclaimed and elects to use sewage sludge for reclamation.

Case 1

The land owner elects to use commercial methods and bears the entire cost of reclamation. If the owner elects to use sewage sludge, however, the cost to the owner may range from zero, as was the case for the Ottawa, Illinois site, to some cost figure negotiated between the land owner and the sludge generator. The cost to the owner would be zero if the sewage sludge generator determines that the sum total of the costs of site preparation, transporting, handling and applying the sludge plus seeding, and or landscaping is less than the costs of other sludge management alternatives, or for reasons not related to costs, may be more desirable.

Case 2

A sewage sludge generator is looking for a management or disposal option and considers reclamation because no other viable alternatives are available; or who finds that strip-mined reclamation is less expensive depending on the agreement negotiated with the land owner; or regardless of cost, the reclamation option may represent the most viable long-term sludge management program.

Case 3

A sludge generating agency either elects to own or obtains a long-term lease of strip-mined lands as part of a long-term sludge management program. The sludge generating agency may be faced with the need to develop a long-term uninterruptable option, especially in situations where other sludge management options are not available, and existing options are being negated by regulatory or other non-cost constraints.

COST COMPONENTS

The cost components used in the comparison analysis fell into the categories of capital costs and maintenance and operation costs. Capital costs include monies expended for consulting services, land, site preparation, equipment and buildings. Maintenance and operation costs include costs for salaries and overhead, equipment, vehicles, fuel and energy, sludge and fertilizer application, farming, environmental monitoring, transportation and miscellaneous items.

Capital Cost Items

Consulting services may include such items as general engineering, geotechnical services, aerial mapping and contouring for projects where large tracts of land are involved, and legal services for land acquisition and obtaining rights of way or easements if public agencies are involved. Land costs are strictly related to purchase of land, while site preparation costs may include monies expended for access road construction, earthworking, clearing and sedimentation pond construction. Equipment costs may include monies expended for sludge pumping stations, pumps, transmission lines and buildings.

Maintenance and Operation Costs

Monies expended for salaries are exclusively used for personnel costs. Equipment costs include expenditures for tractors, plows and other farm implements, while costs for vehicles include trucks and automobiles. Application costs also may include the cost of equipment such as tractors and plows amortized over ten years (e.g., Fulton County project). Farming costs may include expenditures for plowing, seeding or planting and harvesting of crops (e.g., Fulton County project). Transportation costs refer to sludge hauling only, while fuel and energy costs refer to gasoline and diesel fuel and electrical power costs. Monitoring costs unless otherwise noted refer to contract monitoring costs. In the case of the Fulton County project there is an on-site laboratory and resident staff and the monitoring costs in this instance include salaries and overhead, consulting services, equipment and supplies, vehicles, vehicle maintenance and fuel, and laboratory building costs amortized over twenty (20) years.

PRESENTATION OF COST DATA

The form in which the cost data were available presented some difficulties for their presentation in this report. For example, while data for the Fulton County and Ottawa, Illinois projects were available, the level of detail which would be most desirable for this study was lacking. The Metropolitan Sanitary District of Greater Chicago (District), for instance, was interested primarily in total contractor's bid price because they prefer to contract to the single low, responsible, responsive bidder. This procedure simplifies contract administration, and avoids having several independent contractors working on the site simultaneously. Thus, in order to develop a procedure for performing a meaningful cost comparison analysis, some of the data had to be rearranged into similar major components and will be discussed in the cost comparison analysis methodology.

Cost Comparison Analysis Methodology

Data from two (2) Illinois sites located in Ottawa and Fulton County were used to evaluate the cost and environmental impacts for reclamation with sewage sludge. The two sites selected for sludge reclamation have available, reliable cost and environmental monitoring data. Cost data for commercial methods were gathered from actual sites where this method of reclamation was used. It was originally intended to gather environmental and cost data from two (2) commercially reclaimed sites. It soon became apparent, however, that both environmental and cost data from mine spoils reclaimed by commercial methods were very scarce and not readily available for the following reasons:

1. Most commercial reclamation is conducted by small contractors,
2. These operators view their records as proprietary information, and are very reluctant to discuss the financial aspects of their business for fear of losing their competitive advantage, and
3. Reclamation contractors and site owners tend not to discuss the financial aspects of the reclamation job.

Because of the difficulty in finding two (2) commercially reclaimed sites where good parallel records were available, it was decided that data from the literature would be used for evaluating the environmental impact of commercial methods of reclamation.

Cost and Benefits

In the analysis of costs and benefits, the cost components include monies expended for capital, operation and maintenance. Social and environmental factors were accounted for descriptively to determine their significance and impact.

Although cost is certainly a major component in any decision to choose a certain reclamation scheme, the nonmonetary factors may be particularly important when the use of sewage sludge is contemplated. Sewage sludge is a waste product which must be dealt with in some environmentally acceptable fashion. Therefore, although costs for using sewage sludge for reclamation of sites long distances from the sludge generation center may be higher than using commercial methods, it may still be a worthwhile and cost-effective option for a municipality to consider. In some cases where landfill capacity is exhausted, strip-mined reclamation may be the only alternative available to a municipality. Under such conditions, costs become relatively unimportant. Even if alternatives besides strip-mined reclamation were available to the sludge generating agency, it may be more aesthetically, politically or environmentally acceptable to use sewage sludge for this purpose for some specified period.

Private concerns may view sewage sludge in an entirely different perspective. Sludge is a waste product with which they have had little experience. The transportation, application, and environmental monitoring associated with this product is foreign to them. Therefore, even if this product may be less expensive than commercial methods, there may be a natural reluctance to use it. Sludge reclamation may have to be substantively lower in cost as in the Ottawa, Illinois project, where the sludge generating agency determined that it would be cost effective to underwrite the total cost of reclamation by using sewage sludge including long-term monitoring.

In the Ottawa, Illinois project there are distinct benefits for all parties involved. The State agency by approving this project has one less tract of strip-mined land to be concerned about, while the land owner is relieved of the burden of costs for reclamation and monitoring, and the decision to choose between reclamation methods. Finally, the sludge generating agency has available a short-term sludge management alternative which is environmentally acceptable and cost-effective.

SEWAGE SLUDGE VERSUS COMMERCIAL METHODS

As stated previously, the format in which the cost data were available, did not permit direct comparisons to be made without modification. After reviewing the available data, it was decided that for purposes of comparing the costs of sewage sludge reclamation methods with commercial reclamation methods, comparable cost groupings had to be developed. Fortunately, all the data used in this analysis are actual project cost data extracted from contract award documents, actual payrolls and other verifiable expense documents such as invoices. After considerable discussions with project personnel, the following comparable cost groupings were developed for sewage sludge methods:

- sludge treatment
- sludge transportation
- sludge application
- site preparation
- landscaping
- monitoring
- return on crops.

For commercial methods, the following cost groupings were developed:

- site preparation
- landscaping, and
- fertilization.

It is evident from the above cost groupings that more modification of the cost data was necessary to permit direct cost comparisons of the two methods. Thus, a second step in the modification was developed. This second step was concerned primarily with selecting the appropriate cost items for commercial methods to be compared with the single item of sludge application. The cost items for topsoil replacement, fertilizer and lime for commercial methods were consolidated into one cost group for comparison with the cost of sludge application, since it was reasoned that sludge performed the same functions as topsoil, fertilizer, and lime. Similarly, the cost components selected for the site preparation cost group were those for the sedimentation pond, clearing and earthworking.

Thus the major items of costs which emerge for direct comparison from this modification procedure are given in Table 1. The use of the cost groupings for sludge and commercial methods in Table 1 made possible a comparison on the basis of costs. It was necessary to refer to unit cost information in the sections on cost and then develop comparable cost groupings for the comparison analysis.

TABLE 1. MAJOR COST ITEMS USED IN COST COMPARISON ANALYSIS

Comparable cost grouping for reclamation method Sewage sludge	 Commercial
Sludge application and farming	topsoil + fertilizer + lime + vegetation
Site preparation (sedimentation pond + clearing + earthwork)	Site preparation (sedimentation pond + clearing + earthwork)
Landscaping	Landscaping
Monitoring	None or minimal
Return on crops	None or minimal

It should be noted that sludge treatment and transportation costs are not included as major cost items. But, in specific situations both may influence the sewage sludge cost grouping.

While it is possible to develop comparable cost groupings for a cost comparison analysis, the same cannot be said for nonmonetary factors. Nonmonetary factors are situation specific, and do not lend themselves to normalization.

SECTION 5

CASE STUDIES ANALYSIS

RECLAMATION USING SEWAGE SLUDGE

Fulton County Site

Fulton County is predominantly rural with approximately 226,000 ha of land located in West Central Illinois on the west bank of the Illinois River, approximately 290 km (by road) southwest of the City of Chicago. Fulton County has about 6,100 ha of strip-mined land from soft coal mining (5). Strip mining continues in Fulton County and land is being stripped at the rate of 1,214 ha/year (5). In 1973, less than three (3) percent of the strip-mined land was considered to be reclaimed (5).

Fulton County citizens have long been concerned about the effects of strip mining in the county. Their first concerted effort in attempting to solve the problem occurred in 1970 when the County Board of Supervisors and the State Attorney's office formed a special citizens committee to determine what solutions might be proposed so that strip-mined land might again be made productive.

The citizens committee discussed a proposal by Pullman Environmental Services of Chicago to use Fulton County strip-mined land as a landfill site for domestic refuse disposal. The proposal suggested that large tracts of land could be leveled and restored to their original contour. However, it was apparent to the citizens committee that leveling alone was not enough, and that to complete the job of reclamation, something would have to be done to reclaim the cover material on the landfill resulting from previous mining operations. It was at these committee meetings that the use of digested sewage sludge as a soil amendment was discussed. At the direction of the Fulton County Board, the Fulton County Planning Administrator was asked to obtain information on the use of digested sewage sludge for reclaiming strip-mined land. Meetings were held with staff members of the University of Illinois, Department of Agronomy and the local County Extension Advisor. As a result, the Mines and Mining Committee of the Fulton County Board proposed a resolution which stated that the County Board wished to enter into preliminary negotiations with firms that deal with the use of sewage sludge for land reclamation.

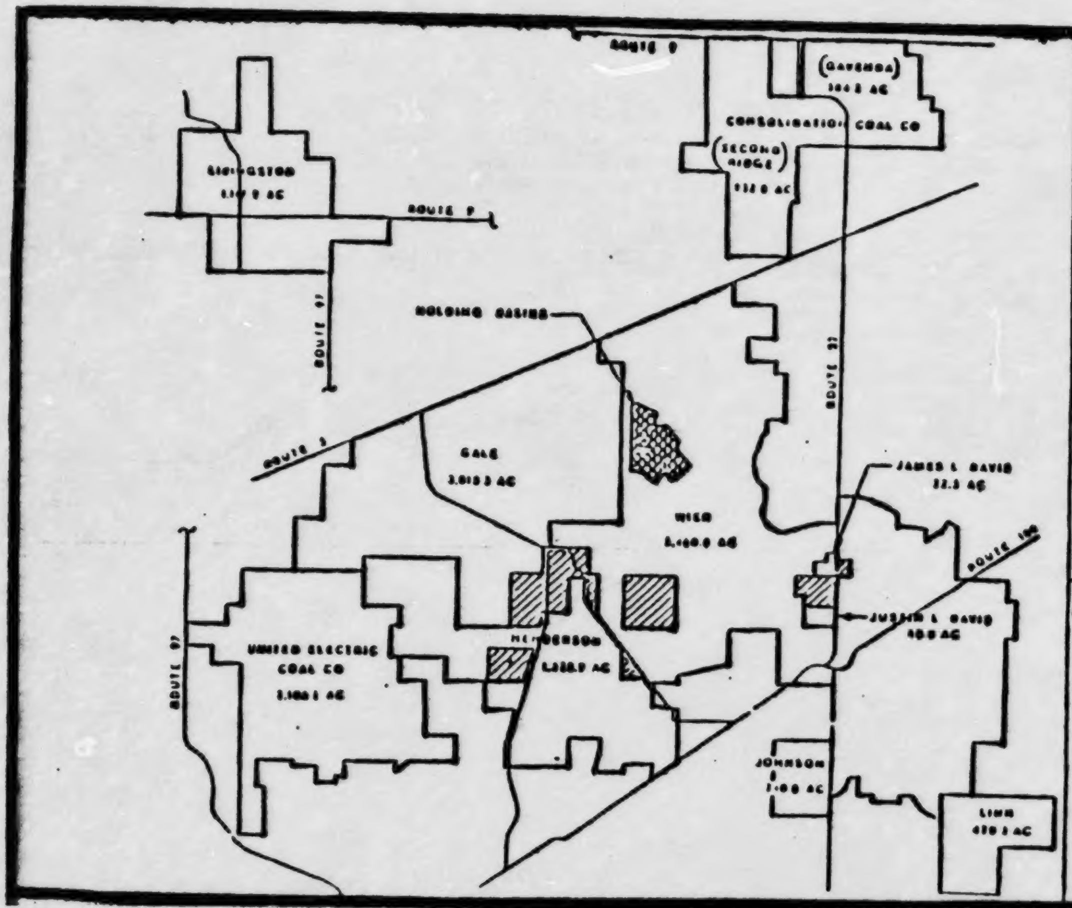
The Mines and Mining Committee of the Fulton County Board began a series of discussions with various mining companies and the Metropolitan Sanitary District of Greater Chicago (District) to attempt to set up a reclamation project in Fulton County. The intention was to set up a lease arrangement between the Fulton County Board and the mining companies and then a release arrangement between the Fulton County Board and the District. This would have allowed direct control of the land by the County Board. However, the mining companies showed no great interest in the scheme and no commitments ever appeared from any mining company.

The District subsequently, purchased initially 2,833 ha of land in Fulton County from three (3) separate private landowners. The District decided that direct ownership of the land was the only alternative open to them given the reluctance of the coal companies to lease land and the unlikelihood of the County Board being able to purchase land for lease to the District.

The District collects and processes wastewater from the City of Chicago and 124 adjacent suburban communities, which includes an area of approximately 222,800 ha. By late 1960, the District was confronted with a serious challenge of managing the residues that were removed from its West-Southwest, (WSW), Sewage Treatment Plant. Historically, solids were either stored in lagoons in a liquid form, dried and sold as fertilizer, or air dried and stored in a landfill site. However, the District was running out of space for lagooning and landfilling (5,6).

The purchase of the land in Fulton County, was therefore a natural outgrowth of the District's need to find a permanent site for its sludge and the Fulton County Board's desire to help solve its strip-mined reclamation problems. Eventually, through land purchases in 1972 and 1975 from five (5) private landholders, the District became the owner of 6,284.1 ha of land in Fulton County. Figure 1 gives a map of the holdings and locations of the land purchases made by the District (7). The goal of the District's program was to regrade the strip-mined land to control runoff, and then apply digested sewage sludge at about 67 t/ha/year to increase the humus content and thereby restore the land to full agricultural productivity.

While the District owns and operates seven (7) wastewater treatment plants, only the sludge produced at two (2) facilities is shipped to Fulton County for land reclamation. The sludges are combined and treated at one of the facilities--West-Southwest Treatment Works. Waste activated sludge and a small amount of primary sludge from the WSW Treatment Works are digested in heated (35^{o}C) high rate anaerobic digesters for 14 to 15 days. During warm weather the solids from these digesters, plus a portion of the solids stored in large holding lagoons near the WSW plant are pumped to barges for transportation to Fulton County, approximately 322 km down the Illinois River. During cold weather, sludge (but without any sludge lagoon material)



FULTON COUNTY LAND RECLAMATION SITE

PROPERTY	HECTARES	PURCHASED
Wier	2,209.9	1970
Henderson	618.7	1970
James Davis	9.1	1970
Justin Davis	16.2	1970
Linn	193.9	1972
Johnson	97.4	1972
Consolidation Coal	613.9	1972
Livingston	452.4	1972
Gale	1,220.3	1975
United Electric	852.3	1975
TOTAL HECTARES	6,284.1	

THE METROPOLITAN SANITARY DISTRICT
OF GREATER CHICAGO
ENGINEERING DEPARTMENT
MAY, 1975 C.K., W.B., M.P.

Figure 1. The holdings and locations of the land purchases made by the District at Fulton County, Illinois.

from the WSW plant digesters is shipped to the Fulton County site. The barges dock at Liverpool, Illinois and the sludge is pumped 17 km through a pipeline to three (3) lagoons at the District's Fulton County site (6).

General Topography of Fulton County Site--

Strip mining activities in the Fulton County (project) site have left steeply sloping spoil mounds and a number of long, narrow lakes with abruptly sloping shorelines scattered throughout the site. Uneven settling of unconsolidated and clayey soils within the mined sections has produced an almost undulating surface. In addition, the project area is covered with rocks and potholes. The application fields developed to date were prepared for agricultural use by leveling to slopes of five (5) percent or less and grading, filling potholes, and removing rocks. Thus, the application fields themselves have a level to gently sloping topography (8).

Geological Characteristics--

The land surface of the Fulton County site is covered with unconsolidated Pleistocene soil deposits in the general area of the site, which nearly obscure the bedrock except near the valleys of major drainage channels (8). A discussion of the bedrock and Pleistocene stratigraphy is presented in Appendix A.

Soil Characteristics--

A study was conducted to identify the soil characteristics of the project site (8) and can be divided into three distinct areas:

Area 1--completely strip-mined land
Area 2--unmined land with a cover of loess over glacial till
Area 3--alluvial land within major stream beds, affected by mining activities

The spatial distribution of these soil areas is presented in Figure 2.

During surface mining operations, the overburden soils and cap rock in Area 1 were removed from the entire area to obtain coal. Therefore, the subsurface of Area 1 consists of cohesive fine-grained soils with pockets and discontinuous zones of boulder-size rock. Numerous depressions were created, most of which have no drainage outlet. Large lakes maintain nearly uniform water levels, which are controlled by culverts.

Based on field pumping tests, laboratory tests, and analysis of existing groundwater conditions, the permeability of the overall mass of mine spoil was estimated to be in the range of 10^{-3} to 10^{-5} centimeters per second (cm/sec) (8). The vertical permeability of soils was estimated by

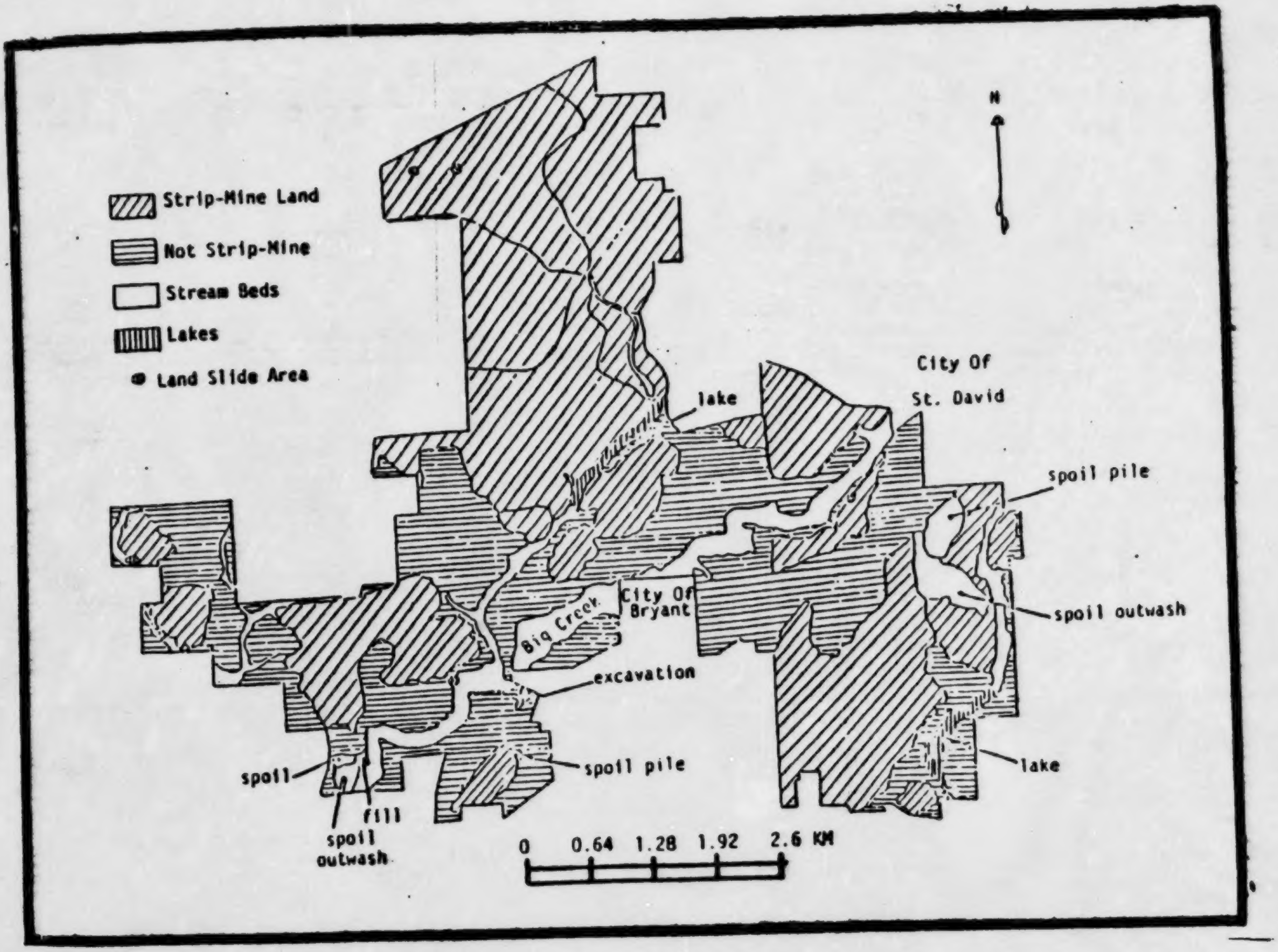


Figure 2. Spatial distribution of soil areas at the Fulton County, Illinois site.

laboratory tests to be from 10^{-5} to 10^{-9} cm/sec (8). According to Casagrande's classification of soils by permeability, these soils are impervious, non-draining or poorly draining (8).

Sludge Application at the Fulton County Site--

From 1972 to 1975 sludge was applied with traveling sprinklers. By 1977 this method was replaced by sludge incorporation with heavy duty, offset disks. Incorporation has several distinct advantages over traveling sprinklers. The incorporation device can apply a greater amount of sludge per application because the sludge is mixed into the soil at the time of application. Also, the reduced visibility in contrast to spray application is an important aesthetic consideration. Incorporation devices can apply sludge to the perimeter of fields, while such application is often spotty with spray application due to the difficulty of controlling the path of the spray under varying wind conditions.

Figure 3 shows a typical application field. Application fields include both non-mined and mined spoiled areas. Each field receiving sludge is bermed and drains to a field runoff retention basin. Each basin is designed to capture a storm event equaling the regional 100-year storm (15.5 cm) (9). Runoff water is released only after it meets the State of Illinois permit standards (total suspended solids, TSS $\leq$99 mg/l, biochemical oxygen demand, BOD_5 $\leq$33 mg/l, and fecal coliform $\leq$494 cnt/100 ml) (9).

Environmental Monitoring Data--

Sludge applied to the Fulton County agricultural fields since 1971 is typified by the 1979 data given in Table 2 (10). The mean total nitrogen content of one metric ton of sludge solids is 40 kg, of which 16.8 kg is ammonia nitrogen making this sludge an excellent source of nitrogen. The sludge is well stabilized after high rate digestion and lagooning, and has a volatile solids content of 42.4 to 51.4 percent.

Table 3 shows the annual and cumulative sewage sludge applications from 1972 through 1979 to selected Fulton County fields. The data give an indication of the quantities of sludge that a municipality can expect to dispose of on an annual basis through strip-mined reclamation. All the fields have been given a total average of 352 t/ha . It should be noted the average is weighted and takes into account only those fields receiving sewage sludge.

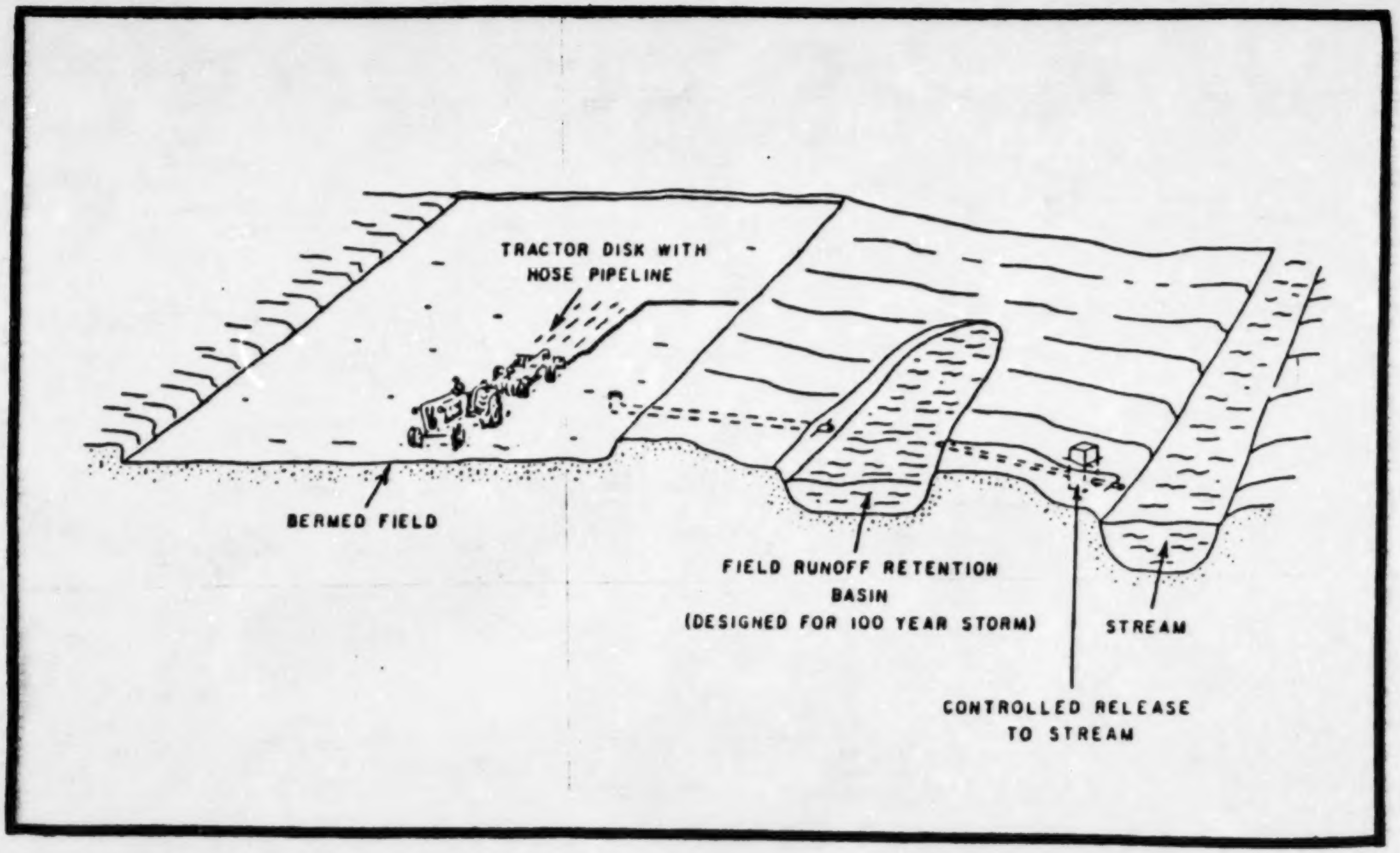


Figure 3. The District's typical field design with runoff water capture system, Fulton County, Illinois.

TABLE 2. RANGE OF THE PRINCIPAL CONSTITUENTS OF THE DIGESTED SLUDGE APPLIED TO FULTON COUNTY FIELDS FROM MAY 6 TO OCTOBER 21, 1979 AND THE MEAN CONTENT PER DRY METRIC TON+ (***)

Constituent	Minimum concentration ++ (mg/l)	Maximum concentration ++ (mg/l)	Mean dry weight dry basis (kg/t)
pH	7.0+++	7.9+++	--
Electrical conductivity	3200*	6800*	--
Total P	1,212	2.060	30
Kjeldahl nitrogen	1,026	2,435	40
Ammonia nitrogen	632	1,072	16.8
Alkalinity as $CaCO_3$	2,250	5,300	64
Cl	176	960	7.01
Fe	1,561	4,790	46.4
Zn	131	226	3.61
Cu	63.0	181	1.77
Ni	13	43	0.46
Mn	12.2	29	0.42
K	40	250	3.1
Na	40	110	1.75
Mg	370	720	10.4
Ca	970	2,600	28.4
Pb	15.0	56.9	0.76
Cr	120	386	4.13
Cd	10.8	19.3	0.28
Al	410	830	12.3
Hg	0.049	0.368	0.0041
Total solids	3.84**	6.04**	1,000
Total volatile solids	42.4**	51.4**	465

+ Results are based on twenty-two weekly composite samples
++ Units are mg/l unless noted otherwise
+++ Values given in pH units
* Values given in μmhos/cm
** Values given in percent by weight

Source: Peterson, J.R., C. Lue-Hing, J.G. Gschwind, R.I. Pietz, and D.R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, 326 pp.

(***) Used by permission of The Pennsylvania State University Press.

TABLE 3. ANNUAL AND ACCUMULATIVE SLUDGE DRY MATTER APPLICATION FOR SELECTED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE*

Mine spoil field number	Quantity of sewage sludge applied (t/ha)								Total applied sludge (t/ha)
	1972	1973	1974	1975	1976	1977	1978	1979	
1	0	0	43	65	120	0	116	0	344
2	0	0	54	41	129	83	36	107	450
3	10	3.4	55	23	83	0	83	14	271
5	0	1.8	52	90	81	0	53	75	353
7	0	1.3	48	50	13	64	59	0	235
25	0	0	22	65	0	112	85	27	311
26	0	0	61	28	98	108	88	17	400
28	0	0	38	82	95	0	79	135	429
30	0	0	45	43	101	126	23	115	453
34	0	0	0	71	18	64	58	59	270
+Weighted average	10	2.2	46	56	82	93	68	69	352

* Used by permission of The Pennsylvania State University Press.

+ Weighted average, takes into account only those fields receiving sewage sludge for the year in the table.

Source: Peterson, J.R., C. Lue-Hing, J.G. Gschwind, R.I. Pietz, and D.R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, page 327.

Nutrient application--Sludge applications to the various fields at the site have been variable because of the difficulty of maintaining constant sludge solids concentrations and variable weather conditions influencing the ability of field personnel to apply sludge (7,10). Table 4 presents data on fields 23, 19 and 15. These data represent the range of sludge applications that have taken place at the Fulton County site since the project began. Field 23 received relatively low sludge amounts, field 19 medium amounts, and field 15 maximum sludge amounts. Sludge applications to field 15 have averaged nearly 82.24 t/ha/year, with a total nitrogen application rate of 3,866 kg/ha, ammonia nitrogen application rate of 1,706 kg/ha, and a phosphorus application rate of 2,537 kg/ha (7).

Soil response--A typical 3-year field rotation schedule consisted of applying sludge for two years and then growing a crop the third year to utilize the available N and provide economic return. Soils are sampled each spring prior to sludge application. Thus, soil pH, organic carbon, and elemental concentrations subsequently reflect soil conditions approximately 5 to 6 months after sludge application had ceased the previous fall.

The effect of sludge application on soil pH in the selected fields is shown in Table 5 (10). In most instances, the soil pH for the calcareous fields decreased somewhat after sludge application. This lowering of pH was most likely a result of organic-N being mineralized to form NO_3-N, and the decomposition of readily degradable organic matter to organic acids. Sewage sludge application resulted in an increase in soil organic carbon content as shown in Table 6 (10). The weighted averages for the fields in Table 6 show that sludge applications generally increased the percentage of organic carbon in the soil each year. The 1979 sampling data showed organic carbon concentrations up to 4.72 percent in field 25 (Table 6).

The soil levels of N, P, and K provide an index for examining the effect of municipal sewage sludge on rebuilding of topsoil. Data obtained on the N, P, & K nutrient levels in the sludge amended mine spoils are given in Appendix B to this report. The available mineral N generally increased each year with sewage sludge applications for mine spoiled fields (Table B-1). By the spring of 1977, considerable amounts of mineral N were present in some fields. Crops are grown every third year to utilize some of the available N. The amount of available P in the sludge amended fields also generally increased with yearly sewage sludge applications (Table B-2). The available P concentrations in the upper 15 cm of most sludge amended fields increased each year. Available P levels were a reflection of the amounts of P added by the sludge. The exchangeable K levels in the application fields were increased by sewage sludge application. Although the amount of K in the applied sewage sludge is approximately 3.1 kg/t (Table 2), land application of sludge generally resulted in higher concentrations of exchangeable K in most fields from 1974 to 1979 (Table B-3).

TABLE 4. SLUDGE SOLIDS AND NUTRIENT LOADINGS TO THREE REPRESENTATIVE FIELDS AT THE FULTON COUNTY SITE

Mine spoil field number		Year	Sludge (t/ha)	TKN (kg/ha)	NH_3-N (kg/ha)	Total P (kg/ha)
23		1975	38.2	2,190	955	1,470
		1976	17.0	809	357	536
		1977	54.6	2,653	1,178	1,869
		1978	55.6	2,725	1,222	1,655
		1979	66.5	2,688	1,118	2,019
		1980	30.7	1,316	451	770
	Total		263.2	12,381	5,281	8,319
19		1973	3.6	813	688	308
		1974	36.7	1,874	1,065	918
		1975	19.7	1,113	486	748
		1976	50.2	2,383	1,054	1,580
		1977	41.4	2,011	893	1,417
		1978	37.4	1,834	823	1,114
		1979	74.6	3,014	1,253	2,264
		1980	98.3	4,219	1,446	2,468
	Total		361.9	17,261	7,708	10,817
15		1974	65.2	3,324	1,890	1,630
		1975	67.4	3,809	1,662	2,558
		1976	133.0	6,320	2,794	4,191
		1977	91.2	4,426	1,964	3,118
		1978	19.5	955	429	580
		1979	129.7	5,239	2,178	3,936
		1980	69.7	2,922	1,024	1,748
	Total		575.7	27,061	11,941	17,761
	Average for 7 years		82.2	3,864	1,706	2,537

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 5. SOIL pH IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE +

Mine spoil field number	Soil pH (pH units)						
	1973	1974	1975	1976	1977	1978	1979
1	--	7.4	6.5	7.0	6.9	6.8	5.9
2	--	7.7	6.8	7.3	6.6	6.8	6.6
3	7.8	8.0	6.8	7.2	6.6	6.5	6.5
5	--	8.0	7.2	7.2	6.5	6.9	6.5
7	--	8.1	7.2	6.8	7.2	7.0	6.7
25	--	6.8	6.8	6.5	6.5	6.5	6.4
26	--	--	7.2	7.2	6.8	6.9	6.8
28	--	7.3	7.3	7.2	6.5	7.1	6.7
30	--	7.4	7.0	7.4	7.0	6.8	6.8
34	7.2	7.4	6.8	7.0	7.0	6.6	6.6
++Weighted average	7.5	7.6	7.0	7.1	6.8	6.8	6.6

+ Composite soil samples from 0-15 cm depths were taken each spring prior to sludge application. Soil pH was determined using 1:1 soil/water ratio.

++ Weighted average (based on analyzed soil samples reported for the year in the table).

TABLE 6. SOIL ORGANIC CARBON IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE +

Mine spoil field number	Organic carbon (%)						
	1973	1974	1975	1976	1977	1978	1979
1	--	0.68	0.75	1.30	2.31	2.82	3.62
2	--	0.54	0.95	1.28	2.74	3.38	3.72
3	1.25	0.86	0.96	1.23	2.62	3.08	3.80
5	--	0.38	1.04	1.14	2.69	2.97	3.89
7	--	0.30	0.59	1.20	0.98	2.69	3.63
25	--	1.28	1.44	2.48	2.11	3.99	4.72
26	--	--	1.16	1.59	2.41	3.59	3.13
28	--	0.66	0.68	1.38	2.34	3.10	3.35
30	--	0.53	0.84	1.06	1.89	3.57	3.57
34	--	0.48	0.17	1.32	1.09	2.50	2.83
++Weighted average	1.25	0.63	0.86	1.40	2.12	3.17	3.63

+ Composite soil samples from 0-15 cm depths were taken each spring prior to sludge application.

++ Weighted average, is based on analyzed soil samples reported for the year in the table.

The concentrations of metals in the soils that had been previously mined (mine spoil) are given in Table 7. For comparison purposes, data for land that has received sludge are also shown in Table 7. Sludge application increased the metal content of the soil. However, there was also a marked increase in organic carbon content (Table 6), a beneficial result of sludge application which might counteract some of the increase in available metals in the soil.

TABLE 7. METALS CONTENT OF MINE SPOIL AT THE FULTON COUNTY SITE BEFORE AND AFTER SLUDGE APPLICATION

	Accumulated sludge applied (t/ha)	
Metals	0 Metal concentration (μg/g dry soil)	277.1 Metal concentration (μg/g dry soil)
Zn	31.7	687
Cd	0.2	51.6
Cu	4.79	259
Cr	1.22	165
Ni	6.7	43.4
Pb	3.52	148
Mn	154	326
Al	509	1,455

Crop response--Corn is the principal crop grown on the reclamation site. This crop which has a high nutrient demand, uses the nutrient in the applied sludge, and provides some economic return for the project. Crop yields have been quite variable and range from excellent to nearly zero (Table 8) (10). Grain yields in 1977 were affected by a drought (10 cm rainfall for June and July) resulting in poor pollination. Adequate moisture and essential elements for crop needs on strip-mined soil are critical for yields of crops grown immediately after land leveling. This stress condition will gradually subside as soil organic matter and element concentrations are built up with successive sludge applications and the structure of soils in the root zone improves.

TABLE 8. CORN YIELDS IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE

Mine spoil + field number	Annual corn yields (t/ha)							
	1972	1973	1974	1975	1976	1977	1978	1979
1	--	--	--	--	--	0.85	--	3.64
2	--	--	--	2.95	--	--	1.37	--
3	3.24	2.86	0.55	3.99	--	2.01	--	5.60
5	--	--	--	--	--	1.16	--	--
7	--	--	--	--	1.62	--	--	2.97
25	--	--	--	--	2.39	--	--	4.10
26	--	--	--	2.80	--	--	--	4.22
28	--	--	--	--	--	0.70	--	--
30	--	--	--	1.61	--	--	1.98	--
34	--	4.12	--	--	5.32	--	--	--
++Weighted average	3.24	3.49	0.55	2.84	3.11	1.18	1.68	4.12

+ Commercial fertilizer was applied to field number 34 in 1973.

++ Weighted average, is based on yield data reported for each year in the table.

Because of the concern relating to the uptake of sludge cadmium to plants, the concentration of cadmium in corn grain harvested from sludge amended fields in Fulton County was regularly measured by the District. With a mean cadmium concentration in the applied sludge of 0.28 kg/t on a dry weight basis (Table 2), some fields had received a total of 135 kg/ha of cadmium by 1979, while cumulative cadmium applied to these fields ranged from 70 to 135 kg/ha through 1979 as shown in Table 9 (10). In fields that had never received sludge, corn grain cadmium levels ranged from 0.04 to 0.46 μg/g (Table 10).

TABLE 9. CADMIUM IN CORN GRAIN FROM SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE

Mine spoil field number	Cadmium applied through each year (kg/ha)							Cadmium in corn grain (μg/g)						
	1973	1974	1975	1976	1977	1978	1979	1973	1974	1975	1976	1977	1978	1979
1	0.0	12	32	68	68	100	100	--	--	--	--	--	--	0.52
2	0.0	16	28	66	93	103	133	--	--	0.29	--	--	0.63	--
3	0.9	18	25	50	50	73	77	--	0.09	0.37	--	0.14	--	0.81
5	0.5	16	42	66	66	81	102	--	--	--	--	0.69	--	--
7	0.3	14	30	33	54	70	70	--	--	--	0.35	--	--	0.46
25	0.0	6.4	26	26	62	86	94	--	--	--	0.22	--	--	0.65
26	0.0	18	26	26	61	85	90	--	--	0.41	--	--	--	0.60
28	0.0	11	36	64	64	86	124	--	--	--	--	0.52	--	--
30	0.0	13	26	56	97	103	135	--	--	0.15	--	--	0.43	--
34	0.0	0.0	22	27	48	64	81	0.01	--	--	0.37	--	--	--
+Weighted average	0.6	14	29	48	78	97	116	0.01	0.09	0.30	0.31	0.45	0.53	0.61

+ Weighted average, is based on Cd data reported for each year in the table.

TABLE 10. CADMIUM IN CORN GRAIN GROWN IN 1979 ON FULTON COUNTY FIELDS NOT AMENDED WITH SLUDGE

Mine spoil field number	Cadmium in corn grain (μg/g)
18	0.46
50	0.30
145	0.04
Mean	0.27

Regulatory restrictions on crops--On September 12, 1979 the U.S. Environmental Protection Agency (U.S. EPA) published "Criteria for Classification of Solid Waste Disposal Facilities and Practices; Final, Interim Final, and Proposed Regulations" in the Federal Register (11). This regulation allows two alternatives for sludge application projects:

1. For land used to produce food-chain crops other than animal feed:

   a. soil pH must be maintained at 6.5 or higher;
   b. by 1987, the annual application of Cd cannot exceed 0.5 kg/ha; and
   c. the cumulative application of Cd is limited by the soil cation exchange capacity.

2. For land used to produce animal feed:
   a. soil pH must be maintained at 6.5 or greater;
   b. there is a facility operating plan showing that the crops will be used strictly for animal feed and if alternative land uses arise, what measures will be taken to safeguard against possible Cd health hazards; and
   c. the land record or deed stipulates that the property has received high Cd application from solid waste and food-chain crops should not be grown.

The District adopted the second alternative, and uses the Fulton County land solely for the production of animal feed. In this case, there is no restriction on the amount of sludge borne cadmium applied.

Runoff retention basin effluent quality--Because of the remote possibility of sludge runoff to nearby streams, each agricultural field is bermed and drains to a field runoff retention basin. These basins are designed to capture and contain the runoff from the 100-year storm (15.5 cm) in the Fulton County region (9).

Under normal operating conditions, the field runoff retention basins are maintained in a drawn-down status. After a rainfall, water samples are taken for analysis of TSS, BOD_5, and fecal coliform densities. If these concentrations are within acceptable Illinois Environmental Protection Agency (IEPA) limits, the contents of the basin are discharged through control structures to the receiving stream. If not, the runoff may be held until sufficient reduction of the offending constitutent is attained; or, at the discretion of the project manager, the flow may be pumped back onto the field serviced by the field runoff retention basin. The District is specifically responsible for reporting the volume and effluent quality of all field runoff retention basin discharges to the receiving streams to the IEPA.

Effluent data for all basins have been grouped into two classifications, which are (1) before digested sludge application to the fields, and (2) after digested sludge application (Table 11) to the fields. The data in Table 11 (9) indicate that there are little differences in the average quality of the effluent from the field runoff retention basins in terms of TSS, and fecal coliform densities before or after sludge application. The mean difference in BOD_5 is about 4 mg/l, but given the accuracy of the BOD_5 test for low values encountered, this difference is rather insignificant.

TABLE 11. RUNOFF WATER QUALITY FROM FIELD RUNOFF RETENTION BASINS**

Source	TSS (mg/l)	BOD_5 (mg/l)	*Fecal coliform densities (cnt/100 ml)
Runoff H_2O before sludge application			
Mean	63	2.8	102
Standard deviation of mean	87	1.4	--
Runoff H_2O after sludge application			
Mean	60	6.0	35.6
Standard deviation of mean	149	5.4	--

* Fecal coliform reported as geometric mean.

Source: Zenz, D.R., J.R. Peterson, D.L. Brooman, and C. Lue-Hing. Environmental Impacts of the Land Application of Sludge. Journal of the Water Pollution Control Federation, 48:2332-2342, 1976.

** Used by permission of Water Pollution Control Federation.

Groundwater quality--Because of the possibility of migration of soluble sludge constituents to groundwater, twenty-five groundwater monitoring wells are sampled on a monthly basis. The monitoring wells were drilled with hollow auger drills to the shale layer underlying the No. 5 coal seam typically 10 to 22 meters below the ground surface. Table 12 gives the annual average data for 1973 and 1979 for two of the monitoring wells at the Fulton County site, wells number 14 and 17. Well number 14 is located in a field receiving sludge application, while well number 17 is located in a field receiving no sludge. There are differences in the chemical constituents between the two wells because the previous strip mining done on the property had disturbed the continuity of the subsurface acquifer. The most significant data to observe, however, are the NO_2+NO_3-N content of the well water. These compounds, NO_2 + NO_3-N, are natural oxidation products of ammonia and organic nitrogen, which are constituents of digested sludge (Table 12).

As can be seen for well number 14, which is located in a field receiving digested sludge, there had been little change in its NO_2+NO_3-N content. The changes in NO_2+NO_3-N that have occurred are similar to those exhibited by well number 17, which is located in a field receiving no sludge.

There appears to be a substantial increase in the sulfate content of groundwater with time in the well located in the sludge application area. This increase is probably due to the soil incorporation equipment uncovering sulfur bearing minerals which are then oxidized to sulfates and leach through the soil.

Surface water quality--The monitoring of the largest stream on the site (Big Creek) was started in 1971 upstream (S1) and downstream (S2) of the District's Fulton County site to determine the effect of sludge application runoff on surface water quality. Water samples have been continuously collected on a monthly basis (7,9). Table 13 presents water quality data for sampling point S2 and shows water at S2 to be of better quality than at S1, indicating relatively clean water coming from the District's Fulton County drainage area. Also sampling point S2 water samples showed similar NO_2+NO_3-N, ammonia nitrogen and iron levels in 1973 and 1979, indicating little change in water quality during that period.

Permits--The District must apply to the IEPA for an operating permit for the Fulton County site. From 1971 to 1975, the site had an operating permit from the IEPA. In 1975, however, the IEPA denied further operating permits to the District and petitioned the Illinois Pollution Control Board (IPCB) to fine the District for alleged nuisance odors that occurred in 1974 and 1975. The IPCB, under Illinois law, has the sole authority to issue fines or impose corrective action. Although the District has not had an issued permit from the IEPA from 1975 to 1981, the site has been allowed to continue to operate under appeal until the matter is settled before the IPCB. However, the District has not been allowed to develop any additional

TABLE 12. MEAN WATER QUALITY OF WELL NUMBERS 14 AND 17 AT THE FULTON COUNTY SITE

Constituent	1973 Sampling period		1979 Sampling period	
	Well 14* (mg/1)**	Well 17* (mg/1)**	Well 14* (mg/1)**	Well 17* (mg/1)**
pH	7.1	7.6	7.0	7.7
Total P	0.12	0.08	0.06	0.04
Cl	19	10	19	13
SO_4	668	113	1,640	138
Total N	1.0	1	0.7	0.2
NH_3-N	0.78	0.21	0.4	0.1
NO_2+NO_3-N	0.03	0.40	0.18	0.07
Alkalinity	741	305	774	262
Conductivity	2,806	745	2,891	796
K	6	1	7	1
Na	293	9	270	7
Ca	264	96	361	79
Mg	216	52	243	45
Zn	15.2	3.2	4.6	1.7
Cd	0.01	0.01	0.01	0.01
Cu	0.02	0.01	0.01	0.02
Cr	0.02	0.02	0.02	0.02
Ni	0.13	0.1	0.1	0.1
Mn	1.76	0.39	2.87	0.34
Pb	0.15	0.09	0.07	0.05
Fe	60.6	14.5	27.4	18.1
Al	1	1	1	1
Hg	0.1	0.1	0.1	0.1
Se	--	--	0.2	0.2
Fecal coliform	2	2	2	2
TSS	--	--	--	--
TDS	--	--	--	--

* Wells 14 and 17 are located in a field receiving sludge and a field receiving no sludge, respectively.

** All units in mg/l except pH, (pH units) fecal coliform (cnt/100ml) Conductivity (μmhos/cm) and Hg (μg/g).

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

TABLE 13. MEAN SURFACE WATER QUALITY OF SAMPLING POINTS S1* AND S2* AT THE FULTON COUNTY SITE

Constituent	1973		1979	
	S1 (mg/l)**	S2 (mg/l)**	S1 (mg/l)**	S2 (mg/l)**
pH	7.9	7.9	7.8	8.0
Total P	0.90	0.46	1.4	0.89
Cl	30	24	36	57
SO_4	269	308	493	562
Total -N	2.8	1.2	1.7	1.3
NH_3-N	0.78	0.59	0.9	0.4
NO_2+NO_3-N	3.12	2.57	3.1	2.17
Alkalinity	271	268	256	257
Conductivity	1,075	1,889	1,118	1,306
K	4	4	6	6
Na	53	66	71	85
Ca	130	174	149	145
Mg	67	109	55	72
Zn	0.1	0.1	0.1	0.1
Cd	0.01	0.01	0.01	0.01
Cu	0.02	0.02	0.01	0.01
Cr	0.02	0.02	0.02	0.02
Ni	0.1	0.1	0.1	0.1
Mn	0.53	0.50	0.41	0.42
Pb	0.04	0.05	.05	.05
Fe	1.2	1.1	0.8	0.8
Al	1	1	1	1
Hg	0.1	0.1	0.1	0.1
Se	--	--	0.2	0.2
Fecal coliform	8,033	4,700	157	132
TSS	--	--	33	46
TDS	--	--	1,099	1,281

* S1 and S2 are stations on Big Creek upstream and downstream of the Fulton County site, respectively.

** All units are in mg/l except pH, fecal coliform (cnt/100 ml) conductivity (µmhos/cm) and Hg (µg/g).

land for sludge application, and the area receiving sludge has remained the same since 1975. The case before the IPCB was settled in 1981 and the Fulton County site was allowed to continue to operate. A new operating permit was issued to the District by the IEPA on January 1, 1982. The permit did not place any special restriction on the District and the site will operate as it has in the past. The new permit requires that the District continue the existing, intensive environmental monitoring.

Social and Aesthetic Issues--

The first land purchase made by the District in Fulton County occurred in 1971. Fulton County public officials were eager for the District to purchase land in Fulton County, because it was believed that sludge applications could restore the land to support row crop agriculture, where previously the land was used mostly for pasture. Cooperation of these local officials was, and is still, excellent. The District established an advisory group in 1971. This group--the Fulton County Steering Committee (steering committee)--is comprised of public officials, representatives of organized civic groups, unattached private citizens, and District staff personnel. The public officials, who sit on this committee, include District Board members, the President of the Fulton County Planning Commission, the Fulton County Planning Administrator, local mayors, a representative of the Governor's office, and the Chairman of the Fulton County Soil and Water Conservation District. Meetings of the steering committee are held monthly for briefings on the site operation by District staff, and discussions on any significant future operational changes.

There has been some public opposition to the use of sewage sludge for reclamation at Fulton County. This opposition is currently minimal, and the operation has continued uninterrupted for nearly ten (10) years. It can be assumed that the operation has gained wide-spread public acceptance, because of the lack of media and public concern about the site since 1980.

Costs and Benefits--

An analysis of the costs of the District's operation in Fulton County must consider the fact that some of the land receiving sludge has not been strip-mined. The total amount of land receiving sludge is 1,024 ha, of which mine spoil land represents 64 percent. The total sludge application to the mine spoil land through 1980 was 252,022 t, or 67.1 percent of the total sludge applied to the site (7).

The District does not keep separate records of costs associated with sludge application to strip-mined land and costs associated with sludge application to unmined land. The District does, however, maintain accurate records of the costs associated with its entire Fulton County operation and has made an extensive cost analysis of funds expended. The costs for the entire site were used in this study to calculate the costs incurred for strip-mined reclamation.

Table 14 contains a listing of the annual and unit costs associated with the Fulton County project (7,13). These costs represent the costs for the entire Fulton County operation including costs associated with unmined land and strip-mined land. Since sludge application to strip-mined land and unmined land has been uniform, unit costs in dollars/dry t ($/dry t) and dollars/hectare ($/ha) for the total project and the reclamation of strip-mined land are nearly the same and are, therefore, assumed to be equal (costs of sludge utilization on strip-mined land and unmined land) in this report.

The maintenance and operation costs given in Table 14 are actual expenditures for the Fulton County operation in 1980. Capital costs are taken from the actual expenditures (1980 Dollars) for contracts (bid prices) at Fulton County.

Land costs represent the actual purchase price (1980 Dollars) for the land amortized at infinite life and 10 percent interest. Site preparation costs represents the amortized total cost for contracts issued to private concerns (lowest bidder) for all earthwork required at the site including field grading, construction of berms, construction of runoff capture basins and all ancillary earthwork. Capital costs for equipment represents the amortized purchase price (1980 Dollars) for all equipment used at the site including pumps, pipes, tractors and ancillary equipment.

Transportation costs for shipment of sludge to Fulton County represent contract costs (lowest bidder) to the District who used a private concern to load and ship the sludge to the holding basins at the Fulton County sites. Sludge application and farming at the Fulton County site are accomplished mainly by private contractors although the District has personnel at the site for overall management of the operations. Sludge application and farming costs represent actual expenditures for private contractors and the District personnel at the site including all ancillary costs.

Monitoring costs shown in detail in Table 15 include the cost of the site at Fulton County, amortization of the building itself and the cost for analyzing samples sent to the District laboratory at Stickney, Illinois.

Only 1,023.5 ha of strip-mined land are actually receiving sludge at the Fulton County site. Thus, for the costs analysis in Table 14, it was assumed that 1,214.1 ha of total land were needed in order to carry out the reclamation of land using sludge and the difference (1,214.1 ha - 1,023.5 ha) was used for roads, sludge storage, etc.

The unit costs for the entire Fulton County operation including sludge transportation, taxes, and monitoring are included in Table 14 and total $288/t ($16,529/ha). However, the sludge transportation costs are much higher than one would probably encounter in most situations because of the long haulage distance of 322 km. Since the District's Fulton County site is not within its corporate limits, taxes must be paid on the land. However, in many other situations where the strip-mined land is owned by the sludge management agency, taxes would not be incurred because the strip-mined land would probably be within corporate boundaries.

TABLE 14. ANNUAL AND UNIT COSTS FOR FULTON COUNTY PROJECT (1980 Dollars)

Item	Annual costs ($)	Unit costs ($/t)	($/ha*)
A. Capital Costs			
Land Acquisition Costs** (purchase cost)	242,142	3.54	236.59
Site Preparation Costs*** (grading, berms, etc.)	795,694	11.64	777.46
Equipment Costs **** (pumps, pipes, etc.)	822,279	12.03	803.44
B. Maintenance & Operation Costs			
Loading & Transportation of Sludge By Barge to Fulton County (by private concern)*****	7,251,470	146.47	7,085.30
Sludge Application and Farming Costs+	7,146,881	104.59	6,983.10
Monitoring Costs (Table 15)	492,239	7.20	480.96
Taxes++	360,056	5.27	351.81
Total Costs	17,110,761	290.74	16,718.65
Annual Return on Crops+++	(193,670)	(2.83)	(189.23)
Net Costs (Total Costs Less Return on Crops)	16,917,091	287.91	16,529.43

*	1,023.5 hectares actually received sludge in 1980
**	Infinite life, 10 percent, 1,214.1 hectares of land
***	20 years, 10 percent
****	10 years, 10 percent
*****	49,509.6 dry t were shipped in 1980
+	68,333.6 dry t were applied to land in 1980
++	1979 Taxes Paid in 1980
+++	Actual receipts in 1980
( )	Benefit to offset costs

TABLE 15. FULTON COUNTY ANNUAL MONITORING COSTS
(1980 Dollars)

Line item	Cost ($)
Salaries and overhead	355,183
Consulting services	25,000
Equipment, supplies, and miscellaneous services	79,000
Vehicle maintenance and fuel	5,000
Annual capital cost*	28,056
Total	492,239

* Building @ 20-year life @ 10 percent and vehicles @ 5 years @ 10 percent.

Source: Personal Communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

Monetary costs at the Fulton County site are quite high due to the large amount of monitoring required by the IEPA. If one neglects the costs for sludge transportation, taxes, and monitoring, the total costs for the Fulton County operation are reduced from about $288/t ($16,530/ha) to $129/t ($8,611/ha).

Summary--

The District now owns about 6,100 ha of strip-mined land in Fulton County, Illinois. Currently, the District has a goal of applying about 67 t/ha/year to the land in order to build up soil organic matter. The District currently is applying sludge to about 1,200 ha of the land, which is planted mainly with corn. This corn is sold to a local cattle-feeding operator.

From 1971 through 1979, certain fields at the site have received maximum total sludge applications approaching 450 t/ha. Soil organic levels have steadily increased from less than 1.0 percent to over 3.0 percent. The site has been extensively monitored, and costs data are carefully documented and available.

The Fulton County site shows the obvious benefits of sewage sludge in the reclamation of strip-mined sites. Soil organic matter and fertility have been significantly increased by sludge applications. A corn crop has been successfully grown resulting in a financial return to the District.

The extensive environmental monitoring program does not indicate any significant adverse impact upon surface water and groundwater. The corn grain produced shows an increase in cadmium concentration due to sludge application, but the site is operating within Federal limitations by selling all grain to a local feedlot.

The costs for the Fulton County site are greatly influenced by the transportation distance and nearly half of the total costs is for transportation. Land costs and the payment of taxes also influence the costs for the project, and would probably not be incurred by other municipalities which would utilize sludge to reclaim land located within their jurisdiction. The site is owned by the District because of its desire to have a permanent site for its sludge management operations and taxes are incurred because the site is outside the corporate boundaries of the District.

The District has experienced some public opposition to the project due to alleged odor generations but, overall, the District has received a positive public reaction to the project. The project has permanently solved a portion of the problem of sludge disposal for the District and has been positively received by the public. These two factors are sometimes of greater concern to a municipality than cost.

Ottawa/Buffalo Rock Strip-Mined Site

Description of the Site and Reclamation Project--

The Ottawa Silica Company (Ottawa, Illinois) owns a 60.7 ha strip-mined site approximately 128 km (by road) southwest of the City of Chicago, Illinois. This site was strip-mined by a coal mining firm and then sold to the Ottawa Silica Company (Company). The Company had hoped to mine the site for sand, but abandoned such attempts because of the high cost of mining the rough strip-mined topography (7). The Company was aware that the site created aesthetic and environmental problems. The site was barren and generated an acid runoff to the nearby Illinois River. The Company wanted to revegetate the site to reduce soil erosion and acid runoff, and make the site more aesthetically acceptable. The site was especially noticeable because it was located near the Buffalo Rock State Park, a scenic State park used by many Illinois residents (7).

The Metropolitan Sanitary District of Greater Chicago (District) became aware of the Ottawa Silica Company site in the late 1970s and approached the Company with a proposal to use some District sewage sludge as a soil amendment for revegetating the Ottawa site. The Ottawa site was an excellent opportunity for the District to demonstrate to private concerns the effectiveness and benefits of using sewage sludge for strip-mined reclamation. Meetings were held between the State of Illinois Abandoned Mine Reclamation Council, the District, and the Ottawa Silica Company. It was agreed that a reclamation effort using sewage sludge would be made on a 0.809 ha portion of the 60.7 ha site owned by the Ottawa Silica Company and the District agreed to pay the total costs for the reclamation. In October 1979, the Illinois Environmental Protection Agency (IEPA) issued a permit (1979-16-DE) for the reclamation of the 0.809 ha site. No special conditions were stated in the IEPA permit. But, the IEPA did require installation of groundwater monitoring wells and collection of all runoff. The site was graded, amended with sludge and seeded in November 1980.

This strip-mined site is located approximately 104 km southwest of the District's WSW plant, and about 4.8 km west of Ottawa, Illinois in LaSalle County. The site is bordered on the east by Buffalo Rock State Park and on the south by the Illinois River (7).

Briefly, the reclamation project entailed the following:

1. Construction of a temporary access road to the Ottawa site.
2. Site preparation to permit unloading and incorporation of lagooned digested sludge from the District's WSW lagoons.
3. Installing groundwater monitoring wells.
4. Establishing surface water runoff controls.
5. Transportation of partially dewatered lagoon sludge.
6. Mixing and incorporation of sludge/spoil mixture.
7. Grading and reshaping of the site.
8. Landscaping of the site.

Site Geology and Soil Condition--

The site had a top cover of 15.3 m of mine spoil, which overlayed a 0.61 m mined out layer of number 2 Illinois coal. The mine spoil had a permeability of 10^{-6} cm/sec and was nearly impervious. The mined-out coal seam was underlain by a 0.61 m layer of clay, which covered the entire site. Underneath the clay layer, there were approximately 22.9 m of medium grained Saint Peter Sandstone and another 22.9 m of fine grained Saint Peter Sandstone. Under the Saint Peter Sandstone was the Shakopee Dolomite, which extended for at least another 45.7 m (7).

The soil covering the site has a pH of 3.0, organic carbon content of 0.05 percent, and an electrical conductivity of 5.0 μmhos/cm (7).

Treatment and Handling of Sludge Used On the Ottawa Site--

The wastewater treatment solids applied at the Ottawa site are the same as those previously described for the Fulton County site. Some of the solids output from the heated (35°C) anaerobic digesters at the District's WSW plant are stored in large lagoons. Over the years, the inventory of lagooned solids had been building up, until 1976, when a slackline dewatering system was developed to dewater the solids to a consistency suitable for handling, trucking, and land application. Briefly, this method, as diagrammed in Figure 4, consists of first establishing a drainage profile within a lagoon so as to facilitate gravity dewatering of trapped water and rainfall runoff through the supernatent drawoff box. The lagoon is then allowed to remain at rest with an established drainage profile through the following winter (14). When winter is over, a slackline cableway system is utilized to further improve lagoon drainage. The system as used is intended to scrape material from the center, upwards toward the sides of the lagoon. The following is accomplished:

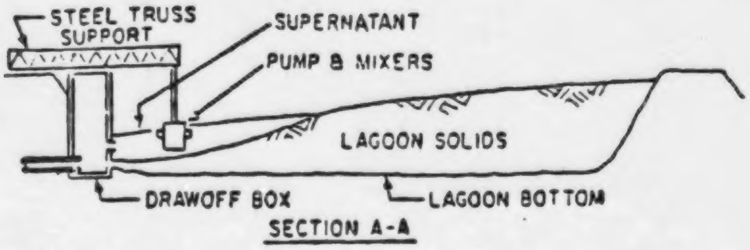
1. In addition to the initial drainage gradient established along the length of the lagoon, a drainage gradient is also established across the width of the lagoon.

2. The slackline first scrapes one side of the lagoon and then the other. Approximately 15.2 cm of lagoon crust (material near the top of the lagoon, the top 7.62 cm of which has undergone appreciable evaporation) is scraped each time, and is piled up along the sides of the lagoon for further dewatering and storage prior to excavation and transportation.

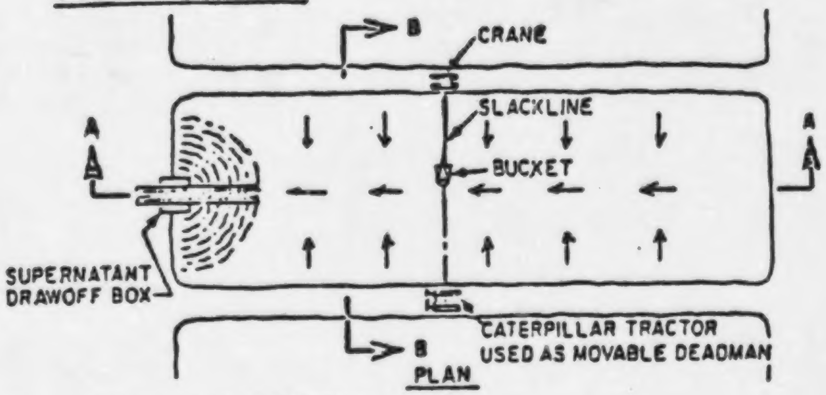
Stored material along the lagoon dikes is removed by dragline into dump trucks.

Description of the Reclamation of the Ottawa Site--

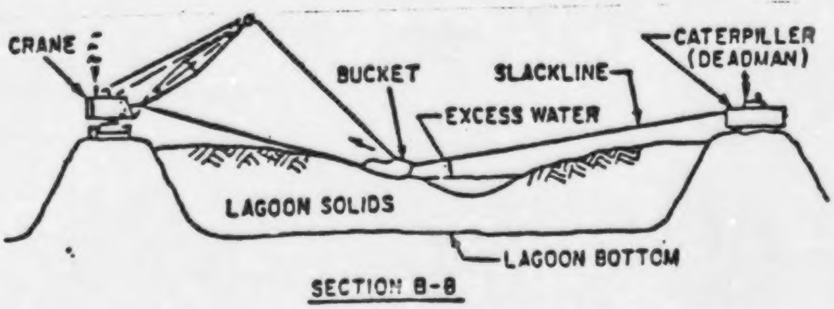
The access road used to transport the lagooned sludge from a nearby public highway to the Ottawa strip-mined site was completed in November 1979. Upon completion of the road, six monitoring wells were installed on the site. Sludge transport and incorporation began on November 5, 1979. A total of 334 truckloads of lagooned sludge from the WSW plant was delivered to the site when the access road was completed on November 16, 1979 (7).



(a) PRECONDITIONING



(b) STRESSING THE SOLIDS



(c) STRESSING AND SHIFTING OF DRIER MATERIAL TO THE SIDES OF THE LAGOON

Figure 4. Lagoon sludge removal at the West-Southwest Sewage Treatment Plant (13).

Mixing of the lagooned sludge with the mine spoil was accomplished by placing the sludge along the crests of the mine spoil ridges, and after partial drainage, the sludge was mixed and pushed into the valleys between ridges. The ridges were then cut down and the valleys filled, allowing simultaneous leveling of the 0.809 ha site. Grading continued through December 13, 1979. The site was graded to minimum slopes of 1 percent and maximum slopes of 20 percent.

The total quantity of sludge transported to the site was 6,116.4 m^3 or 6,398 wet t with an average solids concentration of 29 percent. The total, dry metric tons transported was 1,855. The actual application rate to the site was, therefore, 2,293 t/ha. This sludge application rate was necessary to neutralize the acid pH of the soil to levels that would be compatible with the cultivation of grass and trees.

Landscaping of the 0.809 ha site was accomplished in two steps after the sludge application. A mound was constructed in the southwest corner of the site and nine trees and twenty shrubs were planted. The rest of the site was hydroseeded at the rate of 235.4 kg/ha (134.4 kg fescue and 101 kg of rye). The site was mulched with straw at the rate of 4.48 t/ha. The grass was successfully established on the site as evidenced by a site inspection in the fall of 1981. A vigorous stand of grass was established on the entire site where sludge was applied.

Environmental Monitoring Data--

Sludge Quality--Table 16 shows the constituents of the anaerobically digested lagooned sludge shipped to the Ottawa site (7). The sludge contained about 2 percent total nitrogen and volatile solids of about 30 percent. The sludge was typical of a highly industrialized area like metropolitan Chicago.

Surface Water--Because of the concern about runoff to the nearby Illinois River, a surface water collection basin was constructed at the Ottawa site. The surface water from the sludge application area drained to this basin. No outlet was provided from the basin and water simply evaporated or percolated to groundwater (7).

The surface water collection pond was sampled on two occasions: just before (November 20, 1979), and about 2 months after sludge application (February 28, 1980). The analytical results of that sampling are shown in Table 17 (7). In general, the change in the quality of surface water as a result of sludge application tended toward lower metals and higher nitrogen content.

Groundwater Analysis--Because of concern about migration of sludge constituents to groundwater, monitoring wells were installed at the site and the groundwater was sampled before sludge application began (November 20, 1979) and 1 year later (November 20, 1980). Data for three groundwater monitoring wells are given in Table 18 (7). Although six wells were installed, three of the wells yielded no water and were dry. The data in Table 18 indicate no deterioration in the groundwater as a result of sludge application to the 0.809 ha site.

TABLE 16. CONSTITUENTS IN DIGESTED LAGOONED SLUDGE SHIPPED TO THE OTTAWA STRIP-MINED SITE

Parameter (mg/kg)*	Sampling period in 1979	
	11/5-11/9	11/12-11/16
+ pH	7.6	7.2
++ TS	27.89	30.20
++ TVS	29.82	32.58
++Total P_2O_5	6.96	3.64
++ Total N	2.07	1.94
++ NH_3-N	0.47	0.51
Zn	6131	5828
Cd	445	474
Cu	2098	2381
Cr	7093	4669
Fe	41233	46026
Ni	466	563
Pb	968	1324
K	1076	1656
Na	717	993
Ca	53424	42063
Mg	12191	11921
Mn	341	434
Hg	0.0039	0.00590

* Except where noted otherwise.

+ pH units

++ Parameter concentration is expressed as percent by weight.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

TABLE 17. SURFACE WATER QUALITY AT THE OTTAWA STRIP-MINED SITE

Parameter (mg/l)*	Sampling period: Before sludge application 11/10/79	Sampling period: After sludge application 2/28/80
Alkalinity as $CaCO_3$	0	0
Ammonia-N	21.6	54.6
Boron	0.1	0.1
Cd	0.82	0.12
Ca	260	139
COD	57	93
Cl	17	17
Cr	0.5	0.03
Cu	1.59	0.18
Total hardness as $CaCO_3$	3,416	1,022
Fe	36.8	14.1
Pb	0	0.2
Mg	340	96
Mn	28.7	69.4
Hg	0.0001	0.0002
**pH	4.2	4.3
Phenolic compounds	0.003	0
Total phosphorus	0.46	0.17
K	1.0	6.0
Total solids	5,764	1,666
Na	6	8
Sulfate	4,159	1,217
Al	220	23

* All parameters given in units of mg/l, except where otherwise noted.

** pH values are given in pH units.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

TABLE 18. GROUNDWATER ANALYSIS AT THE OTTAWA STRIP-MINED SITE

Parameter	Sampling period					
	Well No. 1		Well No. 2		Well No. 3	
	11/20/79 Before sludge application	11/20/80 After sludge application	11/20/79 Before sludge application	11/20/80 After sludge application	11/20/79 Before sludge application	11/20/80 After sludge application
	(mg/l)					
Sulfate	4,994	4,360	5,117	7,440	3,776	3,600
NH_3-N	10	2.9	15.0	3.0	10.0	2.8
Mn	78.4	37.5	156	156	46.0	23.5
Fe	398	259	1,082	115	465	56.7
COD	169	108	398	250	133	57
Total solids	5,984	4,710	10,484	9,194	4,950	9,560

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

Costs--

Table 19 gives the costs for reclaiming the 0.809 ha Ottawa site exclusive of environmental monitoring. Unit costs are presented in both dollars/dry t ($/t) and dollars/ha ($/ha). As can be seen, transportation costs represent the largest expenditure at the site. Table 20 presents the costs of environmental monitoring for the 0.809 ha Ottawa site. As can be seen, environmental monitoring represents a small part of the unit costs of Table 19. The total cost of reclamation of the 0.809 ha site, including the cost of environmental monitoring, would amount to $81.14/t of sludge applied, or $186,057.85/ha of land reclaimed.

The District, after completion of the reclamation of the 0.809 ha Ottawa strip-mined site, prepared a cost estimate (7) for reclaiming the remaining 59.9 ha of land at the site. The estimate was based upon the experience gathered at the 0.809 ha site and included several changes in operation that would result in cost savings. The estimate reflected the following changes from the 0.809 ha reclamation effort:

1. Transportation of 60 percent solids instead of 30 percent solids;

2. Awarding of a separate contract for sludge hauling only;

3. Leveling of the strip-mined area before sludge application and experience with the 0.809 ha site indiciated that simultaneous grading, sludge mixing and incorporation probably doubled or tripled the necessary equipment time required at the site. In order to reduce the equipment time at the site, the methodology was revised. The revised methodology was (1) grade and shape the land, (2) then truck and spread the sludge at the rate of 74 truckloads/ha yielding a depth of 33 cm, and (3) finally, achieve sludge incorporation using a D-7 bulldozer pulling chisel plow to a depth of 69.6 cm to attain the desired 50/50 mix of mine spoil to sludge.

4. Use of conventional tractors and agricultural equipment instead of hydroseeding.

The cost estimate to reclaim the remaining 59.9 ha portion of the Ottawa site is shown in Table 21 (7).

TABLE 19. ACTUAL COSTS IN 1980 DOLLARS FOR RECLAIMING THE 0.809 ha OTTAWA STRIP-MINED SITE

Project activities	Total costs ($)	Unit costs ($/t*)	Unit costs ($/ha**)
ACCESS ROAD CONSTRUCTION			
Supervising manpower	1,225.00		
Materials (stone, culvert)	5,733.34		
Contract labor and equipment	12,796.33		
Subtotal	19,754.67	10.65	24,418.62
SLUDGE TRANSPORTATION			
Loading	18,057.35		
Trucking contract	74,056.50		
Subtotal	92,113.85	49.66	113,861.37
SITE DEVELOPMENT AND SLUDGE APPLICATION			
Engineering and supervision	6,500.00		
Contract labor and equipment	21,462.30		
Subtotal	27,962.30	15.07	34,564.02
LANDSCAPING			
Engineering and supervision	160.00		
Trees and shrubs	1,400.00		
Planting	1,510.00		
Contract seeding	1,960.00		
Miscellaneous equipment	490.00		
Subtotal	5,520.00	2.97	6,823.23
GRAND TOTAL	145,350.82	78.35	179,667.24

* 1,855 t of sludge were applied **

** 0.809 ha sludge application area

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

TABLE 20. COSTS IN 1980 DOLLARS OF ENVIRONMENTAL MONITORING OF 0.809 ha OTTAWA STRIP-MINED SITE

Project activities	Total costs ($)	Unit Costs ($/t*)	Unit Costs ($/ha**)
INSTALLATION OF SIX MONITORING WELLS			
Engineering and supervision	125.00		
Well installation contract	4,260.00		
Miscellaneous equipment	585.00		
Subtotal	4,970.00	2.68	6,143.39
LABORATORY ANALYSIS COSTS			
2 Surface water $35/sample	70.00		
6 Well water $10/sample	60.00		
2 Sludge analysis $35/sample	70.00		
Subtotal	200.00	0.11	247.22
GRAND TOTAL	5,170.00	2.79	$ 6,390.61

* 1,855 t of sludge were applied

** 0.809 ha sludge application area

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

TABLE 21. COSTS IN 1980 DOLLARS FOR RECLAIMING THE REMAINING 59.9 ha OTTAWA SITE

Item	Total costs ($)	Unit costs ($/t*)	($/ha**)
Resident engineer and staff	150,000	1.00	2,504.17
Living Expenses	10,000	0.07	166.95
Contract for road building, grading and leveling and sludge incorporation (6 machines operating for 240 hours per month for 9 months at $60/hour)	777,600	5.16	12,981.63
Culvert for roads	3,000	0.02	50.08
Stone for roads	199,800	1.32	3,335.56
Sludge dewatering costs at WSW Plant-150,592.5 t at $26.20/t	3,945,554	26.20	65,869.02
Sludge transportation 11,030 loads at $200/load	2,206,000	14.65	36,828.05
Trees at $3,756.26/ha	225,000	1.49	3,756.26
Seeding at $1,752.92/ha	105,000	0.70	1,752.92
TOTAL COST	7,621,954	50.61	127,244.64

* Based on 150,592.5 t of sludge applied

** 59.9 ha site

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, Research and Development Department, 1981.

It can be seen that the unit costs both in dollars/dry t of sludge applied and dollars/ha reclaimed are lower for the 59.9 ha site in comparison to the reclaimed 0.809 ha site. The total cost for reclamation of the 59.9 ha site is $50.60/dry t or approximately $127,244.00/ha, while the total cost for the reclamation of the 0.809 ha site was $81.41/dry t or $186,058.00/ha. The chief reasons for the unit cost savings for the 59.9 ha site in comparison to the 0.809 ha site are economy of scale, the previously mentioned change in the application method for the 59.9 ha site, and the reduction in transportation cost as a result of shipping sludge with 60 percent solids instead of 30 percent solids.

The cost for transportation of sludge to the Ottawa site is high because of the long hauling distance of 122 km. A sludge management agency would probably not transport sludge to a site this far away except under unusual circumstances. Sludge dewatering costs would be incurred mainly to reduce sludge transportation costs and, therefore, these costs would not normally be encountered in most situations. If the sludge transportation costs and sludge dewatering costs are not included in the total cost for reclaiming the Ottawa site, the total cost would be reduced from $50.60/t ($127,244.00/ha) to $10/t ($24,548/ha).

Summary--

The District developed a proposal to apply sludge to approximately 0.809 ha of a 60.7 ha strip-mined site owned by the Ottawa Silica Sand Company. The 0.809 ha site development was required by the State of Illinois to demonstrate the effectiveness of using sewage sludge. Digested lagoon sludge with a solids concentration of about 30 percent was applied and worked into the soil, after which the site was sowed with grass seed in late 1979. The operation is considered successful by the District and plans for reclamation of the remaining 60.0 ha are underway. The site is equipped with facilities for monitoring the surface water and groundwater quality before and after sludge applications. Cost data are well documented and available. Environmental monitoring did not indicate any adverse impact on groundwater and surface water. Costs for the project were greatly influenced by sludge dewatering and transportation which together represented nearly 89 percent of the total cost for reclaiming the 0.809 ha site.

The District has benefited from the operation because it has found a possible avenue for the management of a portion of its sludge. The site has, to date, not resulted in the disposal of a large volume of sludge, but serves as a demonstration of the usefulness of sludge in reclaiming strip-mined sites. Overall, the Ottawa operation had positive public relations benefits with no negative reaction of any kind, and may serve to influence other private concerns to enter into cooperative agreements with sludge generating agencies for the utilization of sludge for reclaiming strip-mined lands.

RECLAMATION USING COMMERCIAL METHODS

Background

Surface mining of coal has a deleterious effect on the mined area. The groundwater may be degraded during the mining operation. The surface soil is moved and in the past was often buried. In the eastern United States, iron pyrite (FeS_2), which can lead to acid drainage problems, is a prevalent sulfur-bearing mineral in the coal seams and adjacent shale layers. If the pyrite material is placed on or near the spoil surface, the pH of the resulting spoil could range from 2.2 to 3.5. Lignite and sub-bituminous coal fields rarely have acid spoils (15). In some areas of the eastern United States, where the overburden contains sufficient limestone and the pyrite content is low, it is possible to bury the pyrite material and place the existing limestone material nearer the surface. This practice may result in a neutral or alkaline spoil pH. The strip mining process destroys the existing vegetation and loosens the soil surface. This unconsolidated surface is then subjected to both wind and water erosion. Until the spoil is revegetated, the movement of spoil materials will continue. In addition, the movement of water and soluble minerals through the spoil profile and into surface runoff water will be greater on a barren surface.

At most coal mines, a tipple area exists where the coal is cleaned before shipment. The coarse refuse portion of the coal-cleaning operation consists of coal mixed with pyrite, sandstone or limestone, clay, and shale. The refuse produced is usually disposed of in a valley or open field where it is subject to weathering. This is an ideal environment for the oxidation of the pyrite. The restoration of this refuse material is an important part of mine spoil reclamation programs.

Characteristics of the Spoil Material

The topsoil is often buried and mixed with the subsoil and parent materials during the stripping operation. Only very recently have mining operators been stockpiling the topsoil and subsoil to return to the releveled spoils so that the final land area will have the original soil mixture returned to the land surface. If the deeper horizons of spoil are low in shale and pyrite content, these sites may only need N, P and K fertilizers to produce a crop. It is advisable to plant a grass-legume mixture as the first crop because the soils are compacted from the heavy equipment traffic. The fine grass roots and the deep roots of alfalfa will increase water infiltration on the site and the annual ground cover helps stabilize the spoil against erosion. Alfalfa and bromegrass were found to increase the fungal numbers four to eight times in Illinois mine spoils (16).

Grandt and Lang (16) studied coal mine spoils in Illinois. They sampled spoils from 15 counties in Illinois and reported that 5.4 percent of the spoils had a pH of 4.0 or less, 5.5 percent had a pH of 4.1 to 5.4, 16.2 percent had a pH of 5.5 to 6.9, and 72.9 percent had a pH of 7.0 and above. Soils with a pH of 4.0 or less are considered toxic because of their sulfur content. This sulfur usually results from the weathering of sulfurous shale layers. A blue-gray shale from southern Illinois and a yellow shale known as Canton shale from western Illinois were studied in the greenhouse. The blue-gray shale was neutralized and supported legumes after treatment with 90 t limestone/ha. The yellow shale required 134 t limestone/ha to neutralize the acids and permit the growth of legumes (16).

Acid spoil bank material in Ohio that had a pH of 2.4 was treated with 69 t limestone/ha, 560 kg/ha of 0-25-25 fertilizer, and 280 kg/ha of ammonium nitrate. It was then seeded with a grass-legume mixture. Some of the seed germinated in the more acidic areas and then died, even though the limestone was incorporated in the top 15 cm of the site. In these areas, the acid moved to the soil surface during periods of water evaporation. The seeding did become established on part of the experimental site. The pH values were 2.7 on the barren areas and 5.4 on the vegetated area 4 years after liming and fertilization (17). Another study conducted by Sutton involved covering acid spoil material with soil (17). The acid spoil with a pH of 2.3 contained a red shale and was 25 percent sand, 43.7 percent silt, 31.2 percent clay, 1.5 percent total sulfur, 6.6 meq exchangeable Al/100 g, and 45.8 meq exchangeable H/100 g. The electrical conductivity of the spoil was 5.5 μmhos/cm^2. This spoil material was covered with soil to a depth in plots of 5, 10, 15, 20 and 25 cm, and seeded with Kentucky 31 fescue. There was growth on the 10, 15, 20 and 25 cm soil covered plots, but the stand was poor. The 5 cm soil cover was lost to erosion and compaction. The next year these plots were seeded with Korean lespedeza and orchard grass. The lespedza was still growing 4 years later on the 15, 20 and 25 cm of soil cover plots. There was no indication of the acid moving up into the soil material in that experiment, although the root growth was confined to the newly added soil layer. The area was flat and had good drainage (17).

Crops and Crop Responses

The first crop usually planted after a mine spoil is regraded, limed, and fertilized is a grass-legume mixture. This mixture provides the best ground cover and root penetration. The fine root system of the grass can utilize the limited available water very efficiently. Legumes that have been inoculated with specific cultures of bacteria can fix atmospheric nitrogen for plant use. Therefore, only P and K are needed to grow a grass-legume mixture if the soil pH is acceptable. Table 22 gives the mimimum soil pH requirements for some plant species for near-maximum production (15).

Forage mixtures produced on strip-mined land in Illinois are presented in Table 23. The best yields were from mixtures of alfalfa-grasses and birdsfoot trefoil-grasses (16).

TABLE 22. CROP pH REQUIREMENTS *

Crop	Minimum pH for good productivity
Barley	4.8
Bermuda grass	4.5
Blueberries	4.0
Buckwheat	5.0
Clover	5.5
Corn	4.8
Fescue	5.2
Lespedeza	5.5
Oats	5.0
Rye	5.0
Sorghum	4.8
Soybeans	5.0
Sweet clover	6.5
Wheat	5.5

* Used by permission of American Society of Agronomy.

Source: May, D.A. and G.W. Bengston. Lime and Fertilizer Use in Land Reclamation in Humid Regions. In: Reclamation of Drastically Disturbed Lands, F.W. Schaller and P. Sutton, eds. By permission of the publisher, American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. Madison, Wisconsin, 1978, pp. 307-328.

The use of a soil cover on acidic mine spoil in addition to limestone and fertilizer was evaluated at a number of mine spoil sites. A mixture of perennial rye and Kentucky fescue was established on a refuse pile with a pH of 3 at the New Kathleen Mine in Duquoin, Illinois. The refuse was first graded to control drainage, then 34 t limestone/ha were applied, the area was covered with clean earth from 30 to 91 cm in thickness. Afterwards, the surface soil received 13 t limestone/ha and 896 kg/ha of 11-17-23 fertilizer, and was disked and seeded (18). One year later, a good stand of grass existed on the treated refuse.

A coal refuse pile in central Illinois was covered with earth at depths from 30 to 91 cm and was seeded with grasses and legumes. Five years later the vegetation was spotty and the underlying acids were migrating to the soil surface. Figure 5 illustrates the effect of earth cover on plant rooting. In the shallow soil at this location, only the highly acid tolerant, triple awn grass (*A. oligantha*) would grow. The majority of the plant roots remained in the added topsoil. The 60 cm soil depth had the best root growth and was able to withstand drought better (19).

TABLE 23. YIELDS OF FORAGE MIXTURES PRODUCED ON STRIP-MINED LANDS IN ILLINOIS *

Mixture	Year	Yield (t/ha)
Alfalfa and grasses	1949	8.5
	1950	7.9
	1951	6.1
	Average	7.5
Birdsfoot trefoil and grasses	1949	7.7
	1950	7.6
	1951	6.9
	Average	7.4
Mixed legumes and grasses	1949	3.9
	1950	5.3
	1951	5.5
	Average	4.9
Lespedeza and grasses	1949	4.6
	1950	3.8
	1951	4.7
	Average	4.4
Ladino and grasses	1950	7.3
	1951	6.3
	Average	6.8
Red clover and grasses	1949	7.4

Source: Grandt, A. F. and A. L. Lang. Reclaiming Illinois Strip Coal Land with Legumes and Grasses. Bull. No. 628. University of Illinois, Agric. Expt. Sta., Urbana, Illinois, 1958. 64 p.

* Used by permission of Univ. of Illinois Agricultural Experiment Station.

Fair to good vegetative cover was obtained on acidic refuse piles with the incorporation of 268 t limestone/ha. The fescue and bromegrass performed best using this treatment. However, the first seeding failed, and with the addition of more N-P-K fertilizer the second year, the grass grew satisfactorily. The plants lacked vigor and had shallow root systems (17). Follow-up liming and fertilization was essential to maintaining vegetative cover at those sites.

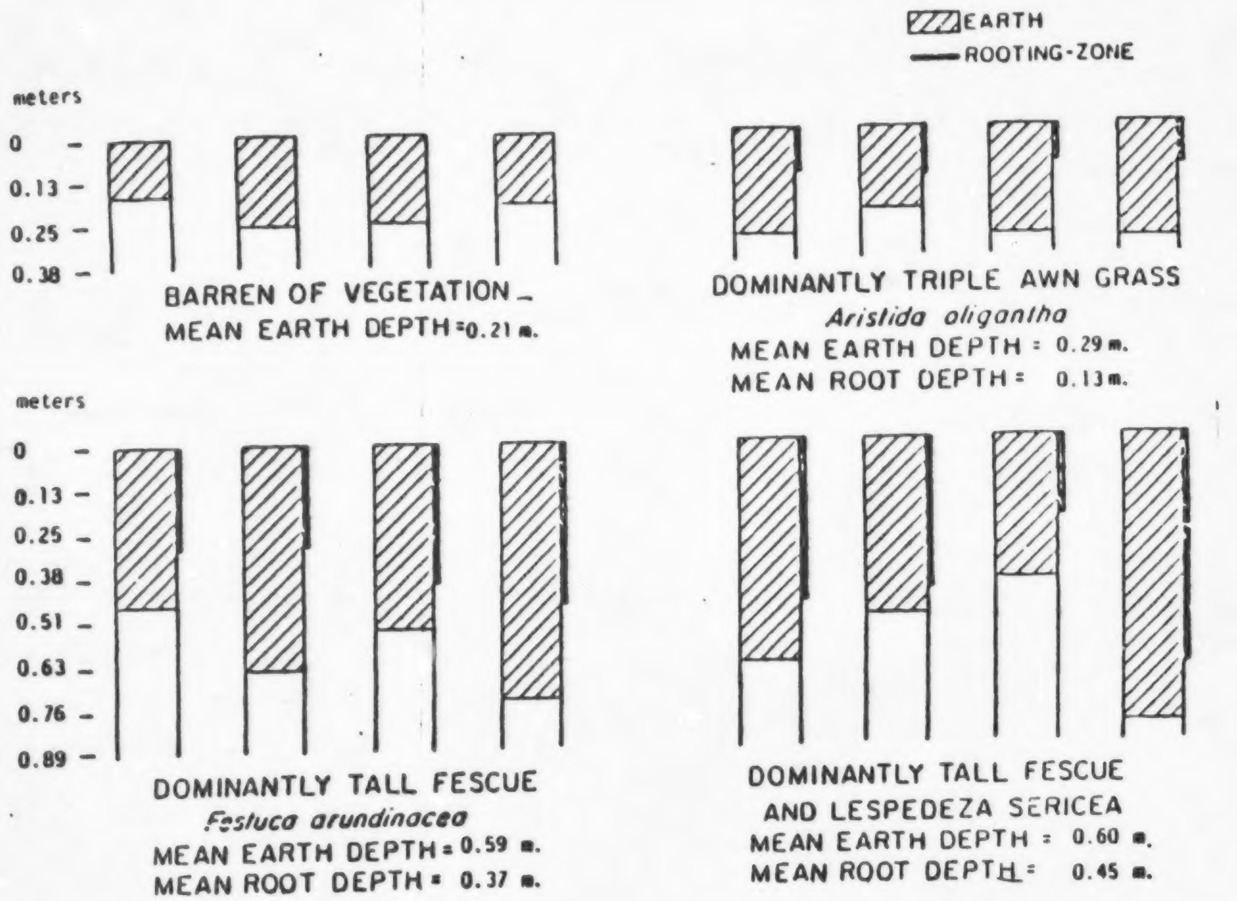


Figure 5. Plant cover and associated rooting depths on the central Illinois coal refuse site.

Water Quality

Surface mining of coal impacts both surface water and groundwaters. Eastern coal usually contains pyrite and acidic shale. The mining activities alter the soil structure and the rate of infiltration on mine spoils. Grandt and Lang investigated infiltration on Illinois spoils using the cylinder method (16). The results are presented in Table 24. They found little differences in infiltration rates between leveled spoils and strike-off spoil tops, but the unreclaimed mine spoil ridges had much higher infiltration rates. The vegetated spoils showed smaller but still significant increases in infiltration when compared to the barren spoils in general.

A study by Peterson and Gschwind (20) evaluated the leachate quality of an acidic mine spoil with a pH of 2.6 in southern Illinois. The leachate from this spoil contained 39 mg acidity/l, 532 mg SO_4/l, 24 mg Al/l, and had a pH of 2.4. During the 110 days of leaching, four volumes (7.1 l) of water were passed through the 1,770 cm^3 of spoil material. The pH of the leachate stayed at approximately 2.4. This acidic leachate increased the solubility of metals in the spoil, and thereby the potential for metal concentration in the groundwater was increased.

Hydrogeological studies of abandoned mines near Ottawa, Coal City, and Harrisburg, Illinois were conducted from 1978 to 1980 (21). Water was sampled from lakes, wells, and lysimeters in the mine spoil and at Harrisburg from off-site wells. The results are presented in Table 25. The groundwater at Ottawa was high in total dissolved solids, sulfates and iron. The Harrisburg groundwater was high in total dissolved solids and sulfate. The groundwater quality of Ottawa and Harrisburg was obviously deteriorated. The Ottawa spoil was high in pyritic shale and the surface ponds drained into the St. Peter Sandstone. The Coal City spoil was predominantly sand with only a small amount of pyrite. The aquifer was isolated by a thick fine-grained Pennsylvanian shale. The Harrisburg spoils consisted of clays, lacustrine silts, and some shale and limestone. Lakes have formed in the area because of the low hydraulic conductivity of the underlying rocks.

A study of an acid coal mine spoil in Grundy County, Illinois has been in progress since 1972. The spoils were graded, limed, fertilized, and seeded in 1972 and 1973. The acidic lake was limed to a pH of 5 to 6. Within a few years the area eroded and the acidic spoil materials drained to the lake, reducing the pH of the water to 3 to 4. The spoils were regraded, limed, fertilized, and covered with soil again in 1979 and 1980. The rate of lime and fertilizer applications was not available. The Argonne National Laboratory (ANL) has been evaluating the water quality of these reclamation efforts since 1980 (22). Water quality observations for the Grundy County study from February 1980 to February 1981 using 38 piezometers in a watershed, which has a lake in the center, showed slight improvement in groundwater quality. But, one year is not enough time to show clear trends. The lake in this watershed decreased in acidity with increases in specific conductivity, sulfates, calcium, sodium, and iron (22).

TABLE 24. INFILTRATION RATES OF FOUR SPOIL TYPES UNDER THREE DIFFERENT PHYSICAL CONDITIONS (LEVEL, STRIKE-OFF, AND RIDGES), AND TWO TYPES OF COVER (BARE AND GRASS LEGUME VEGETATION)+ (*)

Spoil type	Barren (no cover) Physical condition			Vegetated cover Physical condition		
	Level (cm/ha)	Strike-off (cm/ha)	Ridges (cm/ha)	Level (cm/ha)	Strike-off (cm/ha)	Ridges (cm/ha)
Calcareous silty clay (Fulton County)	2.26 ± 0.23	1.90 ± 0.46	23.6* ± 25.6	3.78 ± 1.62	4.65 ± 1.65	34.5 ± 26.2
Calcareous silty shale (Fulton and Knox Counties)	1.78 ± 0.99	1.47 ± 0.96	4.95 ± 2.13	2.31 ± 1.22	2.59 ± 1.22	33.9 ± 15.0
Calcareous silty clay, rock (Perry County)	3.53 ± 0.99	2.56 ± 1.09	17.3 ± 13.4	3.63 ± 1.30	3.66 ± .56	79.7 ± 61.0
Calcareous loam, loessal (St. Clair County)	1.07 ± 1.02	3.05 ± 0.91	7.06 ± 8.38	4.34 ± .08	3.45 ± 2.56	135.3 ± 48.4
Average	2.16	2.26	13.2	3.53	3.58	70.8

+ Each value with its standard deviation is a mean of 10 determinations except (*), for which 20 determinations were used.

Source: Grandt, A. F. and A. L. Lang. Reclaiming Illinois Strip Coal Land with Legumes and Grasses. Bull. No. 628. University of Illinois, Agric. Expt. Sta., Urbana, Illinois, 1958. 64 p.

(*)Used by permission of Univ. of Illinois Agricultural Experiment Station.

TABLE 25. SUMMARY OF WATER QUALITY AT THREE ABANDONED MINE SITES IN ILLINOIS

Site	Parameter (mg/1)	Spoil wells* (mg/1)	Lysimeters* (mg/1)	Lakes* (mg/1)	Drift (mg/1)	Bedrock (mg/1)
Ottawa						
	pH^{+}	6-6.7	3.6-6.0			
	EC^{++}	3,400-4,000	NM**			
	TDS	3,800-5,500	8,000-11,000			
	SO_4	2,450-3,750	NM**			
	Fe	12-400	500-1,400			
	Ca	400-600	320-430			
	Mg	350-750	600-1,500			
	Na	9-100	180-1,090			
Coal City						
	pH^{+}	6.7-8.0	6.9-8.0	6.9-8.6		
	EC^{++}	800-4,600	1,800-7,000	625-1,750		
	TDS	490-5,000	2,400-6,700	500-1,650		
	SO_4	60-3,000	1,400-4,200	420-1,100		
	Fe	0.04-66	0.04-0.25	0.2		
	Ca	60-540	400-515	100-250		
	Mg	40-520	100-600	70-145		
	Na	13-280	47-725	15-29		
Harrisburg						
	pH^{+}	6.5-7.1	3.8	7.1-7.5	6.9-7.1	7.0-7.3
	EC^{++}	4,600-5,300	NM**	5,300-5,350	1,450-2,300	3,000-3,700
	TDS	4,740-5,175	NM**	5,100-5,200	1,250-1,450	2,760-3,370
	SO_4	3,000-3,140	NM**	3,100	530-660	1,730-1,970

(continued)

TABLE 25 (continued)

Site	Parameter (mg/l)	Spoil wells* (mg/l)	Lysimeters* (mg/l)	Lakes* (mg/l)	Drift (mg/l)	Bedrock (mg/l)
Harrisburg (cont'd)						
	Fe	0.6-5.5	14,600	0.2-0.9	0.7-3.9	0.2-3.4
	Ca	450-490	370	450-460	200-220	320-373
	Mg	270-310	780	290-310	60-83	195-230
	Ma	450-550	200	510-610	150-185	210-250

* concentrations given in mg/l, except where noted otherwise.
** NM = not measured.
+ values in pH units.
++ values in μ mhos/cm

Source: Lindorff, D. E., K. Cartwright, and D. L. Herzog. Hydrogeology of Spoil at Three Abandoned Surface Mines in Illinois, Preliminary Results. Environ. Geology Notes 98. Illinois State Geological Survey. Champaign, Illinois, 1981.

Schubert and Prodan (23) presented data from an old pyritic coal refuse and slurry site produced from an underground mine operation. The results should have many similarities to those expected for surface mine wastes. The refuse and slurry from underground mines in southwestern Illinois were deposited on an area underlain by 18 to 24 m of a silty-clay glacial till. The refuse pile was 25 m high and 1.8 ha in area and the slurry material covered 4.5 ha. This mine was active from 1904 to 1924. Before any reclamation was started, 27 piezometers were installed around the site to evaluate the shallow groundwater (< 4.6 m). Residential wells near the site were also sampled. The results of this study in 1976 show that piezometer water samples had a pH range of 2.27 to 6.38, the mean acidity was 4,000 mg/l and the mean sulfate concentration was 6,330 mg/l. The nearest residential well, located less than 70 m from the refuse pile and 30 m from the drainage ditch, was somewhat higher in calcium, magnesium, sodium, and sulfate than the other residential wells. None of these 13 residential wells showed increased dissolved trace metals (23).

After the first hydrological study, the refuse pile was graded to a height of 6 m, covered with 175 t/ha of limestone, disked, and topped with 0.3 m of calcareous, silty-clay loam. The area was fertilized and seeded in the spring of 1977. A good growth of vegetation appeared in the summer of 1977. Forty-five new piezometers were installed in 1977 (1.5 to 9 m depth) along with the two which survived the grading operation. Deeper groundwaters were observed using 16 residential wells. Figure 6 shows the short-term water responses to the 1977 reclamation. Piezometer P7 was set in the base of the refuse, P14 and P15 were in the till beneath the refuse, and R1 was a residential well less than 70 m from the refuse pile and 30 m from the drainage ditch. The exposure of fresh pyritic materials during the grading resulted in a flush of acids, soluble salts and sulfates into the refuse-piezometers (P7, P14, P15). As the groundwater flowed out of the refuse area the acid and sulfate/concentrations decreased.

Table 26 shows the groundwater changes at the reclaimed area. Wells in group A are refuse leachate, group B wells are in till below the refuse, groups C and D are in till at distances of 30 to 50 m from the refuse pile. Wells away from the gob pile contained bicarbonates, showed a drastic drop in acidity, and a moderate reduction in sulfate concentrations. The groundwater quality of the slurry area is depicted by well groups E and F. The concentrations of boron, ammonia, and sodium were higher than in the waters in the adjacent wells. The quality of these waters improved rapidly the farther the distance from the reclaimed area, because of the low hydraulic conductivity of this till and the calcareous materials neutralizing the acid leachates. As the pH increased, more metals precipitated as hydroxides or sulfate salts in the soil. Absorption and cation-exchange also controlled pollutant migration. No contamination of groundwater from acid leachates was detected more than 50 m from the gob pile for this 50-year old coal refuse site (23).

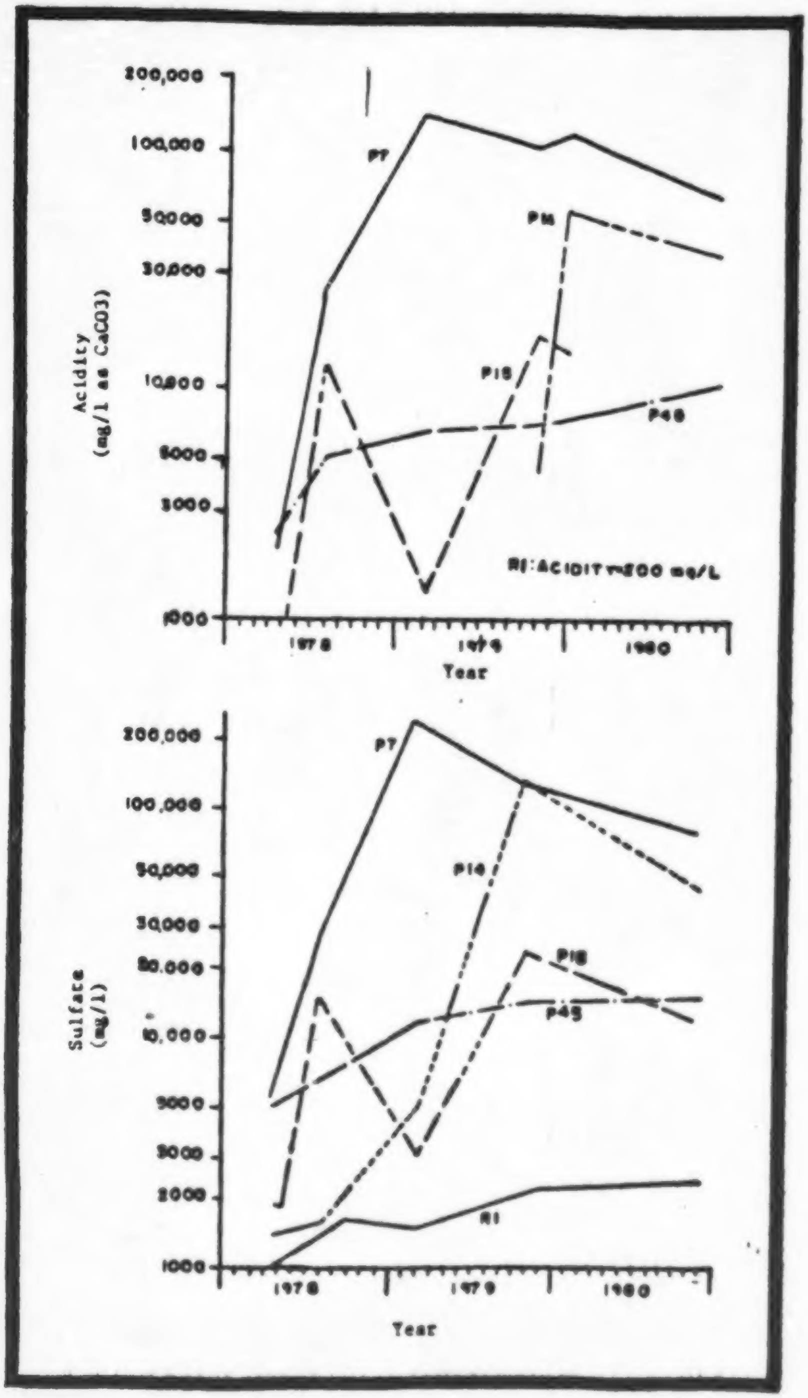


Figure 6. Short-term water responses to the 1977 reclamation, Ottawa, Illinois site.

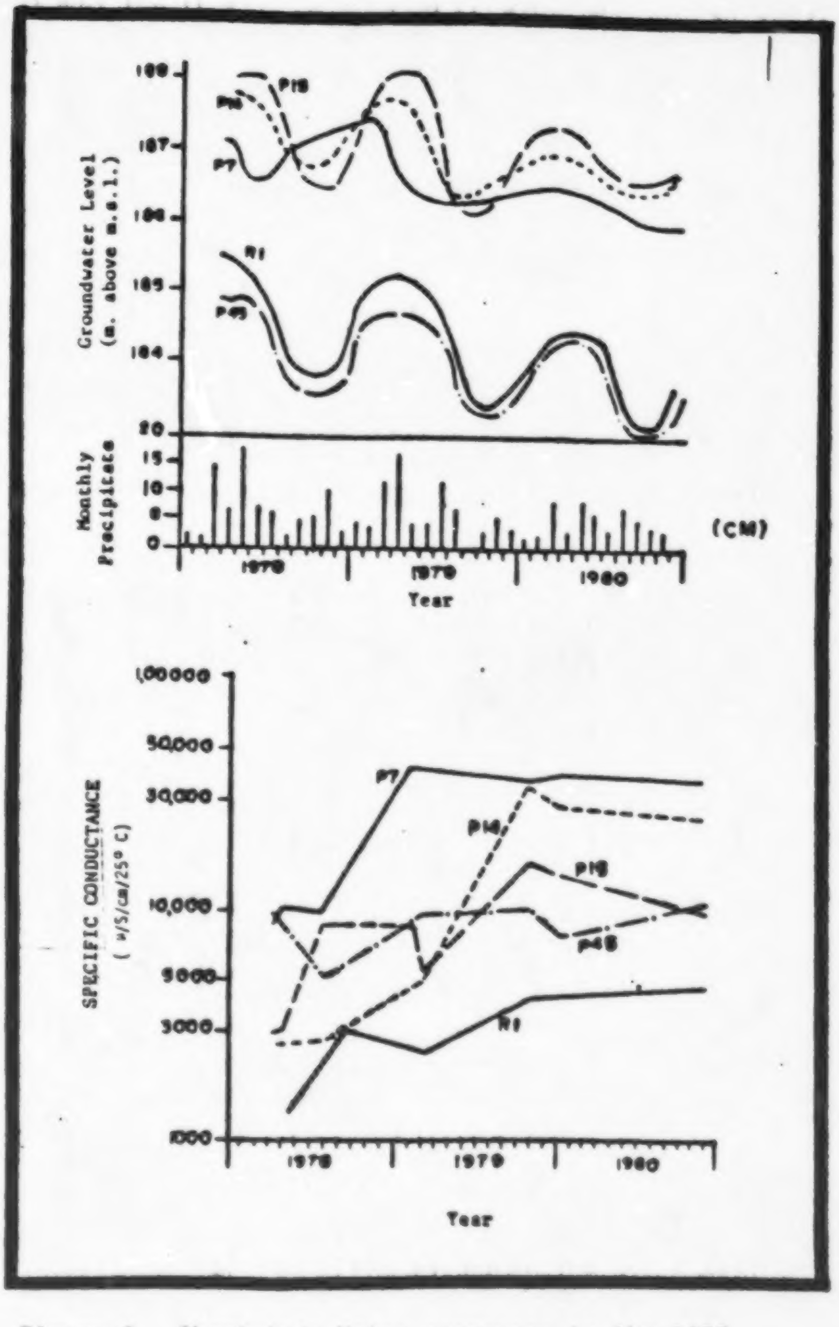
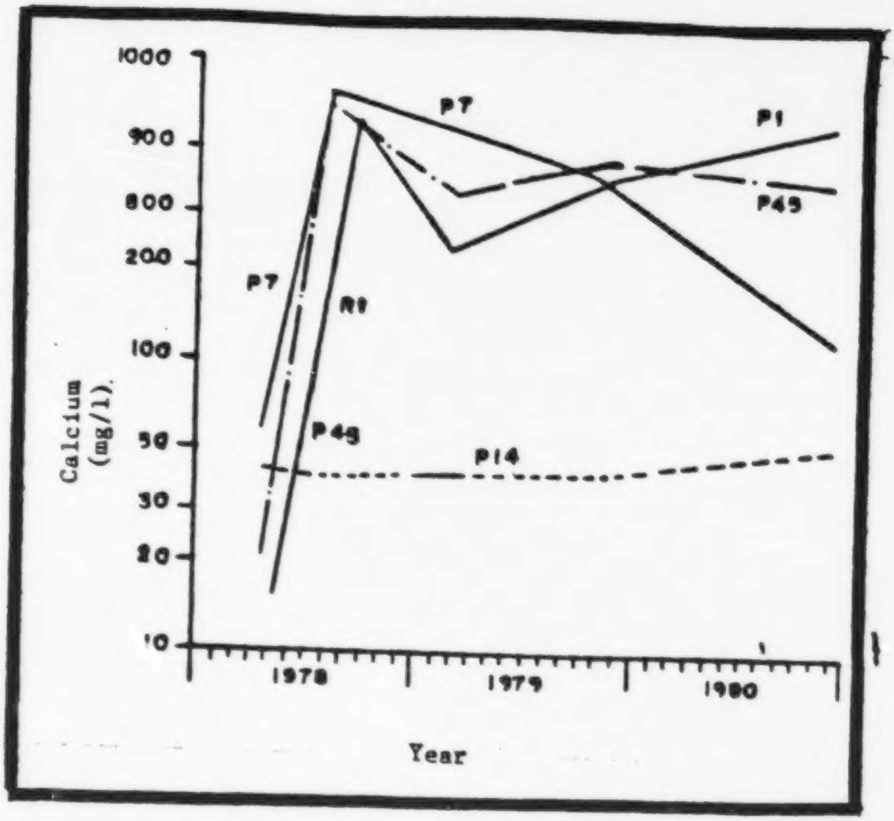


Figure 6. Short-term Water responses to the 1977 reclamation, Ottawa, Illinois site.

(continued)



LEGEND:

P7 & P14 = piezometers in base of refuse
P15 = piezometers in till under the till under the refuse
P45 = piezometers in till <30m from the refuse
R1 = well <70m from refuse pile

Figure 6. Short-term water responses to the 1977 reclamation, Ottawa, Illinois site.

TABLE 26. GROUNDWATER QUALITY* AFTER RECLAMATION, OTTAWA, ILLINOIS SITE *****

Well Group+ Parameters+	A** (mg/l)	B** (mg/l)	C** (mg/l)	D** (mg/l)	E** (mg/l)	F** (mg/l)	G** (mg/l)	H** (mg/l)
Specific Conductance***	14,360	8,170	4,360	2,330	2,350	3,246	2,500	1,320
pH***	3.49	3.88	6.50	6.70	6.93	7.00	7.00	7.10
Eh***	169	146	-30	-64	-104	-92	-78	-14
Acidity***	13,900	7,200	364	90	117	104	140	32.2
Alkalinity***	0	0	220	164	556	582	612	209
Bicarbonate	0	0	268	200	690	614	746	256
Sulfate	20,700	8,750	2,650	1,136	775	1,625	1,325	488
Chloride	18	13	36	18	34.5	62	17	22
Fluoride	0.1	0.65	0.63	0.68	0.59	0.49	0.57	1.0
Boron	4.7	0.96	0.35	0.25	0.62	0.47	0.23	0.40
Silica	94	31	19	22.5	15	17	18	15.5
Nitrate-N	0.40	0.03	0.04	0.5	0.07	0.06	0.10	3.5
Ammonia-N	7.2	1.01	0.76	0.105	3.02	2.96	1.68	0.18
Calcium****	407	450	455	294	201	326	304	125
Magnesium	383	551	421	122	120	209	272	82.1
Sodium	336	231	282	89.3	149	287	124	71
Potassium	13.4	2.5	3.42	0.91	3.4	3.05	4.35	2.2
Aluminum	1,040	216	0.39	0.10	0.10	0.10	0.106	0.09
Arsenic	0.0988	0.0141	0.0024	0.0020	0.0020	0.0020	0.0020	0.0020
Barium	0.0217	0.0218	0.0280	0.0263	0.0352	0.0382	0.0273	0.0325
Cadmium	1.58	0.386	0.013	0.01	0.01	0.006	0.010	0.010
Chromium	0.45	0.030	0.015	0.02	0.02	0.04	0.02	0.02
Cobalt	1.12	1.32	0.10	0.06	0.03	0.05	0.04	0.02
Copper	0.19	0.060	0.015	0.011	0.010	0.008	0.04	0.02
Iron	3,440	1,260	35.0	1.78	4.16	1.22		

(continued)

TABLE 26 (continued)

Well Group Parameters+	A** (mg/l)	B** (mg/l)	C** (mg/l)	D** (mg/l)	E** (mg/l)	F** (mg/l)	G** (mg/l)	H** (mg/l)
Lead	0.37	0.20	0.10	0.09	0.06	0.05	0.07	0.08
Manganese	47.6	75.3	10.9	2.30	3.57	4.77	1.80	0.10
Molybdenum	0.0034	0.0020	0.0032	0.0022	0.0033	0.0027	0.0051	0.0017
Nickel	4.42	2.80	0.17	0.04	0.03	0.07	0.07	0.03
Strontium	0.52	0.81	0.98	0.60	0.59	0.50	0.86	0.40
Zinc	168	55.8	0.77	0.24	0.03	0.026	0.05	0.05

+ All parameters in mg/l, except where otherwise noted.

* Values are median values of all samples collected; large difference often existed for values between wells within a single well group.

** LEGEND:

A = base of reclaimed gob pile (P5-P11, P14, P23)
B = till beneath reclaimed gob pile (P4, P13, P15-17, P21, P22)
C = till less than 30 m from gob pile and affected by acid leachate (P2, P3, P18, P19, P24, P24, P43, P45)
D = till 25 to 50 m from gob pile and moderately affected by acide leachate (P1, P12, P20, P44)
E = saturated slurry material (P27, P28, P31, P32, P36-P41)
F = till beneath slurry material (P29, P30)
G = till around reclaimed slurry material (M19, P25, P26, P3-P35, P42)
H = residential wells (R1-R5, R-7-R10, R12-R18)

*** Specific conductance is reported as μS/cm at 25°C, pH in standard units, Eh in mV, and acidity and alkalinity as mg/l $CaCO_3$ equivalent.

**** Dissolved cations were analyzed from from samples filtered and acidified in the field.

***** Used by permission of Elsevier Science Publishers.

Source: Schubert, J. P. and P. F. Prodan. Groundwater Pollution Resulting from Pyritic Coal Wastes. Presented at International Symposium on Quality of Groundwater, Netherlands National Institute for Water Supply, Noordwijkerhourt, The Netherlands, March 23-27, 1981, Elsevier Science Publishers, Science and Technology Division, Amsterdam.

The surface runoff water from an acidic coal refuse pile at the New Kathleen Mine in Duquoin, Illinois produced 222 kg acid/ha/day (as $CaCO_3$ equivalent). The reclamation procedure was described earlier in the subsection on Crops and Crop Responses. The average acid formation rate on the entire restored refuse pile was estimated at 7.3 kg acid/ha/day (as $CaCO_3$ equivalent). No significant difference in the rates of acid formation were observed on plots covered with 30, 61, and 91 cm of soil (18). These results were based on 2 months of runoff data taken the first summer after reclamation. Long-term water quality data were not available for this site. Long-term survival of vegetation on 30 and 61 cm of soil cover on an acid spoil may not be possible, because during droughty seasons the spoil acids will migrate to the soil surface (19). Consequently, the runoff water quality may not remain as good as reported by Kosowski (18).

Summary

Acid coal mine spoils can be successfully revegetated by using lime, commercial fertilizer, and topsoil. However, on very acidic spoils the vegetation may not survive if the underlying acids migrate upward to the root zone. On very acid spoils the depth of the topsoil should be increased and limestone should be applied to the spoil before the topsoil is added. In all cases, periodic fertilization and liming is needed to maintain a good vegetative ground cover.

These data presented in this subsection also indicate that the water quality of acidic mine spoil runoff is rapidly upgraded after the spoil is covered with topsoil. The duration of this improvement depends on the stability of the topsoil and the growth of the plant cover. Groundwater quality has shown a short-term reduction in acidity and sulfate concentrations following mine spoil reclamation.

Cost Estimates for Reclaiming Strip-Mined Sites Using Commercial Methods

Because both costs and environmental data for specific strip-mined sites that had been reclaimed commercially were not available, the environmental and costs data were collected from many sources. However, only cost data for sites where the costs were actually incurred and documented were used. The cost data for commercially reclaimed sites were developed using two scenarios. In the first scenario (Table 27), an acid soil, strip-mined site with relatively steep slopes was reclaimed to produce a forage crop. In the second scenario (Table 28), a neutral pH soil with flatter slopes was reclaimed to support row crop agriculture. These two scenarios were chosen because they represent the range of mine spoil types found in the United States. In general, mine spoils are acid because of the exposure and weathering of pyrites. However, in some areas mine spoil lands are calcareous and remain neutral. Thus, it is reasonable to conclude that reclamation of these two opposite mine spoil types should reflect the range of costs which could be incurred when using commercial methods for reclamation.

TABLE 27. CONDITIONS FOR COST ESTIMATE - COMMERCIALLY RECLAIMING A STEEPLY SLOPED, ACID SOIL, STRIP-MINED SITE

Scenario 1	Condition at site
Slope	10% or less
Soil pH	3.0
Crop	Grass cover
Erosion	High
Total area to be reclaimed	40.47 ha
Drainage area for sedimentation ponds	60.70 ha
Topsoil depth to be added	30.48 cm
Lime requirements	26.90 t/ha
Area to be cleared	12.14 ha
Fertilizer requirement (5-20-25)	1220.6 Kg/ha

TABLE 28. CONDITIONS FOR COST ESTIMATE - COMMERCIALLY RECLAIMING A SLIGHTLY SLOPED, NEUTRAL SOIL pH, STRIP-MINED SITE

Scenario 2	Condition at site
Slope	5% or less
Soil pH	7.0
Crop	Row crop (corn)
Erosion	Moderate
Total area to be reclaimed	40.47 ha
Drainage area for sedimentation ponds	60.70 ha
Topsoil depth to be added	30.48 cm
Lime requirements	Not needed (neutral soil pH)
Area to be cleared	6.07 ha
Fertilizer Requirement	202 Kg N/ha 101 Kg P/ha 101 Kg K/ha

Cost Information from Several Sites--

Unit cost data for four specific sites actually reclaimed commercially were obtained from the Ohio Department of National Resources (ODNR), Division of Reclamation, Columbus, Ohio (Personal communication, Steven Keller, 1981). The ODNR lets contracts for reclaiming abandoned strip-mined land in the State of Ohio. A breakdown of the unit costs for four recent contracts is presented in Table 29. These costs are the actual contract unit price bid items and prices submitted by the lowest qualified bidder and are not cost estimates for projects. All four sites contained sandy soil with pH values of 3.0 to 4.0.

TABLE 29. UNIT COSTS IN 1980 DOLLARS FOR RECLAIMING FOUR STRIP-MINED SITES IN OHIO

Bid Item	Site Number 1 ($)	 2 ($)	 3 ($)	 4 ($)
Sedimentation Pond *	331.12/ha	--	751/ha	1,309.65/ha
Clearing **	271.81/ha	1,069/ha	822.85/ha	1,853.28/ha
Topsoil	1.43/m^3	.82/m^3	1.43/m^3	1.56/m^3
Fertilizer (application)	253.53/t***	275.57/t+	84.87/t+	137.8/t+
Lime ++	10.47/t	8.81/t	20.90/t	17.08/t
Seed	24.25/Kg	30.86/Kg	22.04/Kg	42.99/Kg
Earthworking	16,687/ha+++	7,173.4/ha#	4,129/ha+++	6,434.6/ha+++

** Per ha of land actually cleared
*** 12-24-24, N-P-K
+ 5-20-25, N-P-K
++ Agricultural limestone
+++ 50 percent of area has slope of 7:1 or greater
# 10 percent of area has slope of 7:1 or greater

Source: Personal communication, Steven Keller, 1981

Slopes were relatively steep and, as indicated in Table 29, 50 percent of the area of three of the sites had slopes greater than 7:1. Because of the sandy soil and relatively low pH of the sites, topsoil was considered necessary for revegetation. All sites were seeded with a grass mixture and the resulting stand was considered to be the final cover crop. There are no plans for any use of the land. The contracts for sites 1, 2 and 4 were let on July 1, 1980, while the contract for site number 3 was let on April 7, 1980.

Spore and Nephew (24) estimated mining costs under various conditions. They found that topsoil costs ranged from \$1.06 to \$1.25/m^3. K.L. Leathers (25) reported the cost of topsoil to be about \$1.19/m^3. Persse _et al._, (26) conducted a survey of strip-mined reclamation sites in the western United States. Table 30 contains the data from their survey. The earthwork and topsoil costs for region D (\$20,867.30/ha) were much higher, because topsoil replacement of 1.53 m depth was needed. The Persse _et al._, data are similar to the Ohio data contained in Table 29 when earthwork and topsoil costs are combined. Evans and Bitler (27) surveyed 20 mines in three regions of Appalachia and the midwest. Their data are contained in Table 31. The data are given in dollars/m^3 (\$/m^3) of topsoil and the range is \$0.32 to \$1.73/m^3. Again, the costs are similar for those in Table 29 when the earthwork and topsoil costs are combined.

TABLE 30. COSTS IN 1980 DOLLARS FOR STRIP-MINED RECLAMATION IN THE WESTERN UNITED STATES

Site No.	Region*	Earthwork & topsoiling ($/ha)	Revegetation ($/ha)
1	A	7,100	213
2	B	2,981	166
3	C	7,948	1,653
4	D	6,766	164
5	D	20,867	803
6	D	1,145	569
7	D	9,698	706

*LEGEND:

Region A - Kansas and Missouri
Region B - East and South Texas, Southern Arkansas
Region C - Arizona, Colorado, New Mexico
Region D - Montana, North Dakota, Wyoming

Source: Persse, F. H., D. W. Lockard, and A. E. Linquist. Coal Surface Mining Costs in the Western United States. U.S. Bureau of Mines Information Circular No. 8737, 1977.

TABLE 31. COSTS IN 1980 DOLLARS OF GRADING AND BACKFILLING IN APPALACHIA AND THE MIDWEST

Site	Type of mining method	Post-mine land use	Cost ($\$/m^3$)
Region I*			
1	Contour	N.A.**	$ -0.74
4	Contour, scrapper haulback	Grazing	1.73
5	Contour, block out	Original contour, grazing	0.82
6	Contour, truck haulback	Grazing	0.95
7	Block cut, truck haulback	Pine forest	0.32
8	Area	Woodland, pasture	0.50
9	Area	Grass, forest	0.65
Region II*			
2	Area	Farming, grazing	0.78
3	Contour, block cut, truck haulback	Grazing	0.46
5	Contour, block cut, area	Pasture, woodland	0.64
6	Area	Pasture	0.46
Region III*			
2	Contour	Pasture	0.51
3	Area	Cropland, grazing	0.60
4	Contour	Farmland, 100% backfill	0.46
5	Area	Pasture, 100% backfill	0.40

* States in each Region

Region I - Alabama, Kentucky, and Tennessee
Region II - Maryland, Pennsylvania, Virginia, and West Virginia
Region III - Illinois, Indiana, and Ohio

** Not applicable

Source: Evans, R., and J. R. Bitler. Coal Surface Mining Reclamation Costs, Appalachian and Midwestern Coal Supply Districts. U.S. Bureau of Mines Document IC-8695, 1975.

Brady and Bowen (28) made an engineering estimate of the costs to recontour (no topsoil replacement) 12 abandoned strip-mined sites. The estimated costs are shown in Table 32. These costs are for recontouring only and do not include topsoil replacement. Costs are similar to the earthwork costs given in Table 29 for the four Ohio sites.

TABLE 32. ESTIMATED COSTS IN 1980 DOLLARS TO RECONTOUR 12 ABANDONED STRIP-MINED SITES IN THE UNITED STATES

Site	Cost ($/ha)	Cost ($/m^3)*
Alabama	38,904	1.32
Illinois	16,998	1.11
Illinois	16,151	0.97
Illinois	21,140	2.34
Kansas	5,567	0.58
Missouri	7,292	0.78
Ohio	19,289	1.23
Pennsylvania	5,261	0.58
West Virginia	23,967	3.44
West Virginia	22,000	3.15
Wyoming	12,212	1.60

* Cubic meter of material moved.

Source: Brady, T. M., and P. Bowen. Costs of Recontouring Abandoned Mined Land. In: Proceedings of the Economics of Mined Land Reclamation, ANL/LRP-TM-20, Chicago, Illinois, September 1981.

Henning and Anderson (29) conducted research on using reclaimed strip-mined land to produce row crops in Iowa. This land had been strip-mined, then recontoured, and covered with topsoil prior to planting row crops. The reclamation cost was $18,218/ha. Over 16 ha of the site were set aside for agricultural experiments where different types of crops were grown. Costs for the operation of the cornplots are shown in Table 33. The corn yields in 1979 and 1980 were 44.2 and 38.96 hl/ha, respectively.

TABLE 33. COSTS IN 1980 DOLLARS FOR GROWING CORN ON RECLAIMED MINE LAND IN IOWA

	Costs for growing corn	
Item	Capital costs ($/ha)	Maintenance and operation ($/ha)
Preharvest		
Machinery	42.25	15.56
Seed	--	26.42
Nitrogen @ 57.32¢/Kg	--	115.64
Phosphate @ 61.73¢/Kg	--	62.27
Potash @ 28.66¢/Kg	--	28.91
Lime yearly cost	--	7.78
Herbicides	--	61.18
Insecticides	--	23.80
Interest on preharvest costs (8 m. @ 15%)	--	34.16
Subtotal	42.25	375.72
Harvest		
Combine	45.37	14.23
Haul	5.56	2.00
Dry	15.01	9.01
Mow-conditioner	--	--
Rake	--	--
Bale	--	--
Handle	4.00	1.00
Subtotal	69.94	26.24
Labor	44.03	--
Land	111.20	--
Subtotal	267.42	401.96
TOTAL COST	669.38	

Source: Henning, S. J. and C. E. Anderson. An analysis of Post-Restoration Agricultural Management at the Iowa Coal Project Demonstration Mine. In: Proceedings of the Conference on the Economics of Mined Land Reclamation, ANL-LRP-TM-20, Chicago, Illinois, September 1981.

Cost Estimate-Reclaiming Steeply Sloped, Acid Soil, Strip-Mined Land--

As discussed previously, Table 27 presents a scenario for which a detailed cost estimate is shown in Table 34. All unit cost figures in Table 34 were taken from the costs contained in Table 29. It was decided that the ODNR 1981 data would be used exclusively for the cost estimating since the costs were the lowest bidder contract amounts for work actually performed. The other cost data described in the previous section were not used, because much of it was based upon estimates. The unit costs for the four Ohio sites are somewhat similar to costs found by others in various parts of the United States.

TABLE 34. COST ESTIMATES FOR SCENARIO 1 DESCRIBED IN TABLE 27

	Unit costs ($)			Total costs ($)		
Sedimentation pond	331	to	1,309/ha	13,400	to	53,001
Clearing	271	to	1,069/ha	3,299	to	12,977
Topsoil replacement	0.824 (2,511	to to	$1.56/m^3$ 4,754/ha)	101,642	to	192,429
Fertilizer	84.9 (103.6	to to	275/t 336.4/ha)	4,192	to	13,612
Lime	8.81 (236.99	to to	17.1/t 459.4/ha)	9,590	to	18,594
Grass cover (seed and application)	22.0 (988.7	to to	43.0/Kg 1,927/ha)	39,995	to	78,012
Total costs	4,442.29	to	9,854.8	172,118	to	368,625

As can be seen in Table 34, the estimate gives a range of unit and total costs for each phase of the reclamation process. This was done since there is always an inherent variability in costs incurred for a particular operation, and strip-mined reclamation is subject to this variability. The range of unit costs was selected by examining the range of the costs for the four Ohio sites shown in Table 29 and eliminating a unit cost from the range if it was not typical. For example, earthworking costs for the four Ohio sites ranged from $4,129/ha to $16,687/ha. If the highest earthworking unit cost (site 2) was eliminated, then the range would be $4,129/ha to $6,434.6/ha. Therefore, the cost for site 2 was not used in the cost estimate for Scenario 1. In a similar manner, other ranges of unit costs were chosen from the cost data of the four Ohio sites. As can be seen the total reclamation cost for the steeply sloped, acid soil, strip-mined land (Scenario 1) ranged from $8,572.33 to $16,291.00/ha.

Cost Estimate-Reclaiming Moderately Sloped, Neutral Soil, Strip-Mined Land--

The cost estimate for Scenario 2 described in Table 28 is shown in Table 35. The unit costs for the sedimentation pond, clearing, topsoil replacement and earthworking are taken from the unit costs of the four Ohio sites (Table 29). Again, these costs were used because they are not estimates and are available for all parts of the reclamation process. As was done for Scenario 1, the range of unit costs was selectively taken from the four Ohio sites by eliminating costs which appeared to be atypical.

TABLE 35. COST ESTIMATES FOR SCENARIO 2 DESCRIBED IN TABLE 28

Item	Unit costs ($)	Total costs ($)
Sedimentation pond	331.12 to 1,309.65/ha	13,400.43 to 53,001.53
Clearing	271.81 to 1,069/ha	1,649.89 to 6,488.83
Topsoil replacement	0.82 to 1.56/m^3 (2,511.55 to 4,754.88/ha)	101,642.25 to 192,429.99
Earthworking	4,129 to 6,434.6/ha	167,100 to 260,408
Total Cost	7,243.48 to 13,568.13/ha	283,793.2 to 512,328.6

The unit costs for fertilizer, corn planting, and harvest were not included in Table 35 since they are continuing annual costs. Herring and Anderson (Table 33) found that fertilizer, corn planting, and harvesting annual costs were about $524/ha (1980 dollars) while return from crops grown on commercially renovated strip-mined land was only about $406/ha assuming a yield of 43.29 hl/ha and taking an average selling price of 1980 corn grain in Ohio (30).

The total cost for reclaiming Scenario 2, as shown in Table 35, was $7,243 to $13,568/ha.

SECTION 6

COMPARISON OF COSTS - SLUDGE RECLAIMED SITES VERSUS COMMERCIALLY RECLAIMED SITES

INTRODUCTION

A primary objective of this project was to develop a comparison of costs for reclaiming strip-mined sites using sewage sludge and commercial methods. It is apparent that it is difficult to make such a comparison meaningful, because of the dissimilarities of the two reclamation methods, and differences in the cost data bases available.

Sewage sludge is produced in significant quantities in urban centers, and therefore, must usually be transported long distances to the strip-mined sites, which are usually located in rural areas. This is true for two sludge reclamation sites documented in this report. Transportation costs could be charged to sludge disposal instead of land reclamation. Commercially reclaimed sites, on the other hand, can utilize materials which are relatively close at hand, usually at the nearby feed and grain cooperative outlet. Fertilizer, lime, seed, etc., are readily available and the costs of the materials usually include shipment and application. Topsoil is also usually available within a short distance from the sites. The four Ohio sites (Table 29) discussed previously utilized topsoil within a short truck hauling distance from the strip-mined sites.

At a sewage sludge reclamation site it may be necessary for the municipality to purchase the land before reclaiming it to insure a constant place for utilization of the sludge. For commercially reclaimed sites, the land has already been purchased for coal mining and the land costs will not enter into reclamation costs. A municipality may have to dewater its sludge to apply the quantities needed for reclamation without excessive surface runoff. Dewatering costs may not be necessary if other sludge management options are adopted. Commercial sites, however, utilize materials which are readily adaptable for application without further processing.

Another consideration in comparing costs for commercially reclaimed and sludge reclaimed sites is the differences in the restraints imposed upon municipal agencies, and the private contractors who usually reclaim commercial sites. Municipalities often utilize their own personnel for at least a part of the reclamation process as was the case at the Fulton County and Ottawa sites. Labor costs for municipalities are usually dictated by the union labor costs associated with urban centers. Labor and operation costs for private contractors near the rurally located strip-mined sites are usually lower than that for urban centers. Therefore, the costs developed here for the Ottawa and Fulton County sites, where municipal sludge was used for reclamation, are higher than would be incurred if a private contractor were used by the municipality for reclaiming a particular site, or if a private strip-mined owner should use these same services.

There is an inherent problem in translating any costs for one locality or situation to another specific locality or situation. The costs of lime, fertilizer, topsoil, etc., are very dependent upon site specific situations and the cost components given in this report may not be directly transferable to another locality. A cost comparison was made between commercially reclaimed sites and sludge reclaimed sites, but it should not be concluded that one method will be more or less economical for a particular situation simply because of the cost data cited in this report. Any decision between commercial methods and sludge for reclaiming a particular site should be made based on the characteristics of the site and the availability of reclamation options. Also, there are many intangible factors involved in a decision between sludge and commercial methods of reclamation which have nothing to do with cost.

COST COMPARISON-SLUDGE VERSUS COMMERCIAL METHODS

A cost comparison between the two sludge sites (Ottawa and Fulton County), and the two commercially reclaimed scenarios was prepared with due regard to the inherent differences between the two reclamation procedures. For purposes of comparison, costs for the sludge sites included only those costs associated with the operation after the sludge is delivered. Sludge transportation and sludge processing costs were not included in the cost comparison. These cost components could more rationally be applied to sludge processing rather than reclamation, since they would probably be incurred regardless of the disposal option used by the municipality.

For the Ottawa site, the cost estimate for reclaiming the remaining 59.9 ha site was used for comparison purposes. Forty percent of the monitoring costs for the 0.809 ha site was used because the monitoring of the remaining portion of the site was determined not to be as extensive. For the Fulton County site, land costs were not included in the cost comparison. These costs would not normally be incurred by a municipality reclaiming a strip-mined site and indeed were not incurred for the Ottawa site. Table 36 gives the unit costs for the Ottawa and Fulton County sites with the conditions noted above. As can be seen costs in dollars/ha ($/ha) range from $9,044.95 to $26,803.81 for the total costs of reclamation at the two sites.

TABLE 36. COSTS FOR THE OTTAWA AND FULTON COUNTY SITES FOR COMPARISON WITH COMMERCIALLY RECLAIMED SITES

Cost component	Fulton County site		Ottawa site	
	($/t)	($/ha)	($/t)	($/ha)
Monitoring costs	7.20	480.95	1.12	2,256.24
Staff costs	--	--	1.06	2,671.12
Roads, buildings, and sludge application	--	--	5.16	12,981.63
Sludge application and farming	116.62	7,786.54	--	--
Site preparation	11.64	777.46	--	--
Materials for access road	--	--	1.34	3,385.64
Landscaping	--	--	2.18	5,509.18
TOTAL	135.46	9,044.95	10.86	26,803.81

A listing of the range of unit costs for commercially reclaiming the two scenarios described is presented in Table 37. The two scenarios correspond to scenario 1 where a top soil had to be produced (transported to the site in Scenario 1, and built up on the site at Ottawa), and where it was only desired to produce a permanent vegetative cover. The Fulton County case corresponds to Scenario 2. In these cases, the land is considered to be permanently renovated to a condition where row crops can now be grown.

TABLE 37. COSTS FOR COMMERCIALLY RECLAIMING TWO SITES*

Cost component	Scenario 1 (Table 27) ($/ha)	Scenario 2 (Table 28) ($/ha)
Sedimentation Pond	331.12 to 1,309.65	331.12 to 1,309.65
Clearing	271.81 to 1,069	271.81 to 1,069
Top soil replacement	2,511.55 to 4,754.88	2,511.55 to 4,754.88
Earthworking	4,129 to 6,434.6	4,129 to 6,434.6
Fertilizer	103.59 to 336.36	NA
Lime	236.99 to 459.45	NA
Grass cover	988.27 to 1,927.65	NA
Total Cost	8,572.33 to 16,291.59	7,243.48 to 13,568.13/ha

* Details for scenarios 1 and 2 are given in Tables 27 and 28, respectively.

A comparison of the costs of the sludge reclaimed sites (Table 36) and commercially reclaimed sites (Table 37) indicates that commercial reclamation may be less expensive than sludge reclamation, since the Ottawa site costs ($/ha) are outside the range of the total costs of the two commercially reclaimed sites. This higher cost is partly due to the higher union scale wages which prevail respectively at Peoria, Illinois and the Greater Chicago area. Also, a direct comparison between the two types of reclamation neglects the fact that the degree of reclamation achieved at any of the sites was not the same. For example, the Ottawa site utilized a one-time sludge application rate of 2,293 t/ha, while for the Fulton County site some fields received total sludge applications as high as 575.7 t/ha through 1980. It is not possible to determine exactly the amount of sludge that would be equivalent to a particular commercial reclamation practice unless data were available for two identical sites where both methods were utilized.

To facilitate a comparison between the two methods of reclamation, a range of reclamation costs were calculated to achieve various reclamation objectives. For the Fulton County site, costs were estimated based upon sludge loading rates needed to achieve various soil organic matter levels. At the Fulton County site, soil pH levels were neutral and, therefore, the buildup of soil organic matter was the main objective. Approximate sludge loading rates to achieve 1, 2 and 3 percent organic matter are, respectively, 100, 200 and 300 t/ha, based upon District soil data (Tables 3 and 6). Costs for these sludge loading rates using the Fulton County unit costs are contained in Table 38.

For the Ottawa site, sludge was applied once at a total loading of 2,293 t/ha. This loading was needed to neutralize the low soil pH and promote grass growth. Other sites could require quite different sludge applications depending on soil conditions. In general, sludge application rates of 1,000 to 2,500 t/ha are required to reclaim acid strip-mined sites depending, of course, on specific soil and site conditions. Costs were, therefore, calculated using the Ottawa unit costs for sludge applications of 1,000, 1,500, 2,000 and 2,500 t/ha, and these costs are shown in Table 38.

TABLE 38. COSTS FOR VARIOUS RECLAMATION OBJECTIVES BASED UPON UNIT COSTS FOR THE FULTON COUNTY AND OTTAWA SITES USING SEWAGE SLUDGE

Fulton County		Ottawa		
Total unit costs ($/ha)*	Resulting soil organic matter (%)	Total unit costs ($/ha)**	Total sludge application (t/ha)	Resulting soil pH
13,546	1	10,860	1,000	neutral
27,092	2	16,290	1,500	neutral
40,638	3	21,720	2,000	neutral
---	---	27,150	2,500	neutral

* Costs to achieve soil organic matter content of 1-3%.

** Costs to neutralize soil pH and promote growth of grass cover.

Commercially reclaimed sites require various amounts of topsoil replacement depending on soil and site conditions to achieve reclamation. Some states such as Illinois require up to 121.92 cm of topsoil for reclaiming strip-mined sites. Costs for commercially reclaiming the two described scenarios were calculated for topsoil replacement of 30.42, 60.84, 91.26 and 121.68 cm and are given in Table 39.

TABLE 39. COSTS FOR VARIOUS RECLAMATION OBJECTIVES BASED UPON THE TWO SCENARIOS DESCRIBED IN TABLES 27 AND 28 USING COMMERCIAL METHODS

Commercial Fertilizer Renovation		
Scenario 1 total unit costs ($/ha)	Scenario 2 total unit costs ($/ha)	Top soil (cm)
8,572.33 - 16,291.59	7,243.48 - 13,568.13	30.42
11,083.88 - 21,046.47	9,755.03 - 18,323.01	60.84
13,595.43 - 25,801.35	12,479.61 - 23,077.89	91.26
16,106.98 - 30,556.23	14,778.13 - 27,832.77	121.68

Tables 38 and 39 show the wide range of costs that occur depending upon the reclamation objective sought. For the Fulton County unit costs, reclamation costs ranged from $13,546 to $40,638/ha depending on the soil organic matter level to be achieved. For the Ottawa site, the unit costs ranged from $10,860 to $27,150/ha for total sludge applications ranging from 1,000 to 2,500 t/ha. For the two commercially reclaimed scenarios, total unit costs ranged from $7,243.48 to $30,556.23 for topsoil additions of 30.42 to 121.68 cm. A review, of the estimated costs in Tables 38 and 39, suggests that municipal sludge application can be roughly equivalent in cost to commercial methods for strip-mined reclamation.

The cost data collected here do indicate that in some situations, the cost of commercially reclaiming strip-mined sites may be less expensive than that using municipal sludge. However, even if this is found to be true for a particular site, it still may be desirable for sludge to be used under certain circumstances.

A private landowner of strip-mined property could be convinced to use municipal sludge for reclamation if the municipality will do the renovation at a cost not exceeding that for commercial reclamation. In this way, the private company does not pay anymore than it would if commercial reclamation methods were used, and the payment made by the private landowner to the municipality helps offset sludge management costs. Of course, the net cost for sludge management must be considered in light of other alternatives (such as landfilling, incineration, etc.) but it is possible that aesthetic, social, or political reasons may prompt the municipality to choose strip-mined reclamation even if it is more expensive than these alternatives. It is far more likely that a municipality will not be able to receive any reimbursement for strip-mined reclamation of a privately owned site. However, the cost factor in this case becomes even less relevant, since the municipality is not competing with commercial reclamation methods. The municipality offers to reclaim the land at no costs if the overall cost of disposal, with no payment for renovation from a private landowner, is competitive with other sludge management alternatives.

In another situation, a municipal sludge management agency may actually purchase land that needs renovation. The Metropolitan Sanitary District of Greater Chicago has actually purchased land at Fulton County, Illinois for this purpose, as noted previously. It is believed that the cost of land is offset by the advantage of having a permanent location and a long-term uninterruptable solution to the sludge management needs. In this case, cost of renovation by commercial methods is irrelevant because this option was not considered.

A comparison of reclamation costs by sludge versus commercial methods is only pertinent where someone is willing to pay for the costs of the reclamation itself. A comparison between sludge and commercial methods does, however, establish the credit that can be claimed by the sludge generator against the total cost of sludge management if someone is willing to pay for the reclamation. Besides municipalities engaging directly in renovation projects, there is an opportunity for entrepreneurs in this field as well. The sources for revenue are the municipalities which must dispose of sludge, and State authorities or private firms (such as mining companies) which may be willing to pay renovation costs. It appears that the major source of funds would be municipalities, since the costs for renovation using sludge may in some cases be higher than commercial methods. It appears that a great demand for renovation with sludge could be generated by municipalities by offering to do the renovation for a portion of the cost of commercial methods or for no cost at all to the private land owner.

SECTION 7

INSTITUTIONAL, SOCIAL, AND ENVIRONMENTAL ANALYSIS

INSTITUTIONAL AND SOCIAL ANALYSIS

Because sewage sludge is generally thought of as a waste product which must be disposed of or utilized in some fashion, it is obvious that decisions as to how to manage this material cannot be based solely on cost.

Municipal agencies are public bodies which must address the needs and desires of the population they serve. Often the public is unwilling to accept a sludge management option, even when it can be shown to have the lowest cost. Therefore, a municipal agency may decide to adopt the use of sludge for strip-mined reclamation simply because it may provide better public relations by being more aesthetically acceptable to the general public, than a landfill or incinerator complex. Therefore, the municipal agency may find that the use of sludge for strip-mined reclamation is the only practical alternative available. In most cases, the municipal agencies must weigh a variety of issues when choosing a sludge management option; one of these usually being cost. Land reclamation using sewage sludge offers the municipality a beneficial use of the organic matter and nutrients in the sludge. Beneficial use is a net benefit to society in that a waste product (sludge) is not buried (landfilled) or destroyed (incinerated), but used in some productive way. Sludge and strip-mined reclamation are natural partners, since two environmental problems can be solved at the same time.

The disadvantage of sewage sludge is the presence of many trace elements which could adversely affect surface water, groundwater and marketability of crops produced at reclamation sites. Normally, as was discussed for the Ottawa and Fulton County sites, environmental monitoring may be required, thus placing an additional economic burden on the municipal agency or, in some cases, a private concern (e.g. a mining firm). The municipal agency must also be concerned about transporting sludge to strip-mined sites outside of its jurisdiction. Often, wastes coming from one locality to another can be viewed adversely by the population in close proximity to the sludge reclaimed strip-mined site. This adverse reaction may be due to a concern about possible adverse environmental impacts or a local reaction to an outsider bringing wastes into their home town.

If sewage sludge is going to be used by private companies for reclaiming strip-mined land, there are additional factors which must enter into their decision. Private companies will undoubtedly place great emphasis on the cost of sludge versus commercial methods. However, private companies must consider the social, political and aesthetic factors as well. Many private companies are concerned about environmental issues and may adopt sludge for reclamation in spite of its cost. Public relations may enter into the decision, of a private company depending on the public reactions to the use of sludge for reclaiming a strip-mined site. Of course, all these factors must be evaluated when a company considers a particular reclamation project.

Commercial methods of reclamation are somewhat attractive to private companies, because familiar equipment and material are used. Sewage sludge requires equipment with which they may be unfamiliar and many companies are lacking in the technical expertise needed to plan and conduct a sewage sludge reclamation project. Therefore, many private companies may not even seriously consider sewage sludge for reclamation simply because the concept is foreign to them.

Lastly, there is a reluctance on the part of some private companies to become involved with municipal agencies. Many companies believe that municipal agencies are difficult to work with because of "red tape", and that the reclamation process will be slow and many obstacles will be placed in their path, because of the many regulatory restraints that may be imposed.

The choice between commercial methods and sewage sludge for strip-mined reclamation is a complex matter which has many facets. Any municipality or private concern must consider, not only cost, but the many social, institutional and environmental issues before deciding upon either reclamation method.

ENVIRONMENTAL ANALYSIS

The results of the environmental monitoring at the Ottawa and Fulton County sludge reclamation sites indicates that municipal sewage sludge does not adversely affect groundwater, surface water, soil, or crops when properly managed. The data from these two sites show that the use of sewage sludge for strip-mined reclamation is a highly satisfactory procedure since the alkaline pH of the sludge restores the neutral pH of acid soils, as well as improving the soil condition due to the nutrient and organic matter content of the sludge.

The Fulton County site is producing corn with a cost value of approximately $200,000 annually, while the Ottawa site has a vigorously growing stand of grass cover. Both sites were extensively monitored with no significant adverse effects noted in the environmental monitoring.

The environmental effects of commercial reclamation methods for strip-mined reclamation were also studied by means of a literature survey, since adequate information could not be gathered from case studies. This literature survey revealed that commercial methods would not negatively affect groundwater, surface water, soil, and crops if properly managed. But, it appears that commercial methods of reclamation may have a short-lived effect on acid soils, because there appears to be a tendency for the underlying acids to migrate upward to the root zone and affect the growing plants.

It appears, therefore, that sludge may have a more permanent, beneficial effect, in a given situation, in keeping a good vegetative cover on renovated strip-mined lands. This permanent beneficial effect may tend to make the sludge renovation of strip-mined land more attractive even if the costs for sludge reclamation may sometimes be more expensive.

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APPENDIX A

GEOLOGICAL PROPERTIES OF THE FULTON COUNTY SITE (8)

Outcrops of bedrock reveal that the geological formation consists of shales and sandstones, of the Pennsylvanian Age Carbondale Formation and several strata of coal limestone beds. Figure 7 shows a typical stratigraphic profile. A soft gray shale known as Canton Shale, approximately 12 to 18 m thick, lies immediately beneath the surface soil deposits. This shale is underlain by 0.3-0.6 m of gray, fossiliferous limestone known as Saint David Limestone. Beneath this stratum are 1.2 to 1.8 m of black shale, which merges into a high-quality coal designed as No. 5 or Springfield coal. This coal seam has a thickness of 1.3-1.5 m. The relatively shallow depth and high quality of this coal has led to considerable strip and shaft mining throughout the general area. The coal is underlain by soft clay to shale and several other thin strata of limestone and shale. These layers have a total thickness of approximately 1.5-2.4 m.

The bedrock surface is covered by a 9 to 15 m mantle of glacial drift or drift-related deposits. The bottom layer is composed of a silty clay to clay silt matrix resulting from glacial till during the Illinois Glacial Era. Illinoisian glacial till is topped by a windblown silt material known as loess, which often reaches thicknesses of 6 to 9 m in this general area. Soil borings on the project site indicate a thickness ranging from 9 to 12.1 m averaging about 6 m. Past coal mining operations have modified this stratigraphic profile.

The uppermost bedrock strata and the unconsolidated sediments have been removed and remolded into a generally similar but variable soil mass.

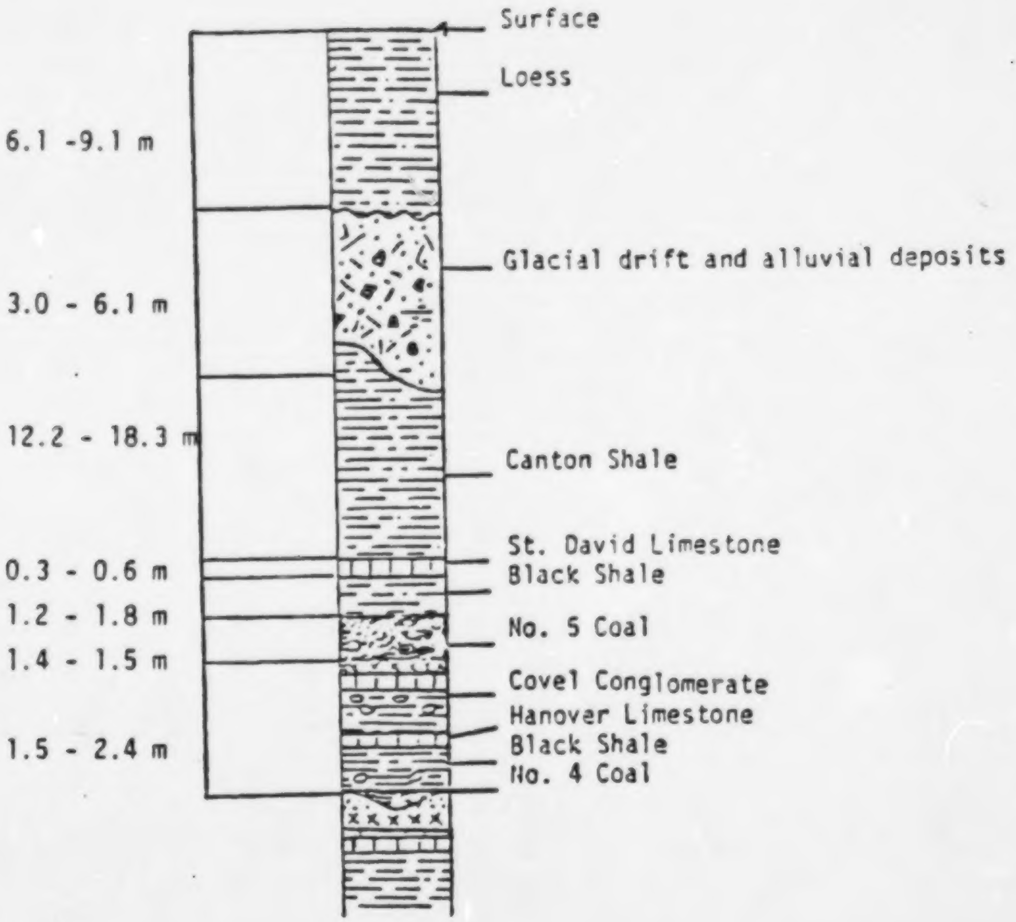

Figure 7. Typical stratigraphic profile in the project area.

APPENDIX B

PLANT NUTRIENT LEVELS IN SOIL AT THE FULTON COUNTY SITE (10)

Tables B-1 through B-3 contain data on the nitrogen (Table B-1), phosphorus (Table B-2), and potassium (Table B-3) content of spoils amended with sewage sludge at the Fulton County site.

TABLE B-1. AVAILABLE MINERAL N^+ IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE**

Mine spoil Field number	Available N (μg/g) Year sample taken 1975	1976	1977	1978	1979
1	32	65	123	21	156
2	62	48	232	44	137
3	37	43	225	28	224
5	37	77	206	20	120
7	60	86	68	26	248
25	74	90	38	68	210
26	114	55	127	42	261
28	76	71	211	33	385
30	60	49	126	52	239
34	17	80	88	53	221
*Weighted average	60	66	144	39	220

+ Available mineral N consists of exchangeable NH_4-N and NO_3 +NO_2-N. Determinations were made on 0-15 cm composite soil samples.

* Weighted average, is based on analyzed soil samples reported for the year in the table.

Source: Peterson, J.R., C. Lue-Hing, J.G. Gschwind, R.I. Pietz, and D.R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, 330 pp.

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TABLE B-2. AVAILABLE P[+] IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE**

Mine spoil Field number	Available P (%) Year sample taken 1974	1975	1976	1977	1978	1979
1	9	10	115	160	240	280
2	9	13	121	171	226	333
3	20	12	115	162	191	258
5	7	17	182	150	218	344
7	9	20	220	139	217	287
25	14	15	121	109	139	497
26		30	94	196	167	523
28	11	9	117	172	177	572
30	10	11	74	122	242	558
34	19	3	123	88	352	452
*Weighted average	12	14	128	147	217	410

[+] Available phosphorus was determined by extraction with 0.03N NH_4F+0.025N HCl. Determinations were made on 0-15 cm composite soil samples.

* Weighted average, is based on analyzed soil samples reported for the year in the table.

Source: Peterson, J.R., C. Lue-Hing, J.G. Gschwind, R.I. Pietz, and D.R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, 331 pp.

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TABLE B-3. AVAILABLE K$^+$ IN SELECTED SLUDGE AMENDED FIELDS AT FULTON COUNTY, ILLINOIS LAND RECLAMATION SITE

Mine spoil Field number	Exchangeable K (%) Year sample taken					
	1974	1975	1976	1977	1978	1979
1	77	127	150	204	243	282
2	65	136	114	210	261	259
3	104	141	160	220	265	178
5	57	133	122	191	249	319
7	71	124	146	118	180	227
25	95	175	190	144	215	256
26		152	99	149	185	179
28	65	104	129	200	256	216
30	61	121	98	158	318	199
34	60	251	108	115	166	217
*Weighted average	73	146	132	171	234	233

+ Exchangeable potassium by extraction with 1N NH_4OAC. Determinations were made on 0-15 cm composite soil samples.

* Weighted average, is based on analyzed soil samples reported for the year in the table.

Source: Peterson, J.R., C. Lue-Hing, J.G. Gschwind, R.I. Pietz, and D.R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, 332 pp.

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